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How digital concept maps about the collaborators' knowledge and information influence computer-supported collaborative problem solving

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Abstract For collaboration in learning situations, it is important to know what the collaborators know. However, developing such knowledge is difficult, especially for newly formed groups participating in a computer-supported collaboration. The solution for this problem described in this paper is to provide to group members access to the knowledge structures and the information resources of their collaboration partners in the form of digital concept maps. In an empirical study, 20 triads having access to such maps and 20 triads collaborating without such maps are compared regarding their group performance in problem-solving tasks. Results showed that the triads being provided with such concept maps acquired more knowledge about the others' knowledge structures and information, focused while collaborating mainly on problem-relevant information, and therefore, solved the problems faster and more often correctly, compared to triads with no access to their collaborators' maps.

Keywords Computer-supported collaboration · Computer-supported collaborative problem solving · Group awareness · Knowledge and information awareness

Introduction

In our information society, computer-supported collaboration becomes increasingly important. However, efficient computer-supported collaboration is not easy to achieve. One of the reasons for this problem that is often cited is the reduced contextual information in such settings (Kiesler et al. 1984). However, in this paper, we direct our attention to another problem that may cause difficulties in computer-supported collaboration but that, to date, has not been given much consideration in researching computer-supported collaborative learning (CSCL): The problem refers to not knowing what the partners know

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and occurs when group members, who are collaborating computer-supported, do not know each other. Research results of other fields, such as social cognitive psychology or discourse psychology, have shown how important it is for collaboration to know what the collaboration partner(s) know. However, the acquisition of such knowledge about the knowledge of others is difficult (cf. Nickerson 1999), in our opinion, especially in CSCL settings with its reduced contextual information. In this paper, a solution for this problem is suggested and its appropriateness is tested in an empirical study.

First, we discuss the importance of computer-supported collaboration and its inherent problems. Then we explain why it is important in group situations to be informed about the others' knowledge and why it is difficult to develop accurate knowledge about what others know. Further, we describe that the problems increase for group members who do not know each other and who must collaborate computer-supported. Subsequently, a solution approach is illustrated before the empirical study investigating its appropriateness is described. The paper ends with a discussion and conclusions.

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The importance of computer-supported collaboration and inherent problems

In the era of an information society and globalization, collaboration over distance becomes increasingly important: Due to the ever-increasing amount of knowledge in different fields, there has also been an increase in the specialization of experts. Therefore, many problems have become increasingly complex and require contributions from people with diverse expertise. As these experts often cannot meet in person due to, for example, time constraints, there is a need to collaborate on a computer-mediated basis.

Imagine the following situation: Due to environmental problems, the spruce forest in a specific area is at high risk. Three spruce experts who have different knowledge of pests, pesticides, mineral nutrients, and fertilizers and who are located at three famous institutions are ordered to rescue this spruce forest. Due to other obligations, they do not have time to meet in person and, therefore, have to contribute to the solution of this problem on a computer-supported basis.

Computer-supported collaboration allows group members to work together although they are spatially distributed. However, despite this spatial flexibility of computer-supported collaboration and other advantages (cf. Fjermestad 2004), research results also show that efficient computer-supported collaboration is not easy to achieve. For example, according to Kreijns et al. (2003) interaction between the group members will not automatically occur just because the technology used allows social interaction. Following Janssen et al. (2007), groups who are collaborating on a computer-supported basis often have interaction problems, especially problems in communication and coordination. Also, according to Malone and Crowston (1994), coordination as the process of "managing Q1 dependencies between activities" (p. 90) is quite demanding in a computer-supported setting. As a reason for these kinds of problems in computer-supported collaboration, one often finds references in the literature to the reduced contextual information, such as nonverbal communication or emotional signals, as compared to face-to-face situations (Kiesler et al. 1984). Therefore, it is important that CSCL environments provide learners with information that they need to collaborate effectively. In this context, it should be pointed out that CSCL environments may even include and provide information which is not available to the learner in normal face-to-face situations. This advantage has to be used in order to find a solution to the following problem.

Especially in computer-supported collaborative learning settings, another important reason may cause problems in collaboration, namely, not knowing what others know: A reason that to date, has not yet been given much consideration in CSCL research.

The importance of knowing what others know in collaborative situations

In CSCL settings, quite often group members do not know each other. Referring to our example, it is not unusual that enlisted experts who are asked to solve problems jointly do not know enough about each other. However, as different research approaches described in the following all demonstrate, it is important for collaboration that a group member knows what his/her collaborators know.

First, in the field of discourse psychology, empirical studies on communication (e.g., Fussell and Krauss 1989a,b) have shown that the behaviour of a specific person with regard to others is strongly influenced by the person's knowledge about what the others know: For example, in research on audience design, evidence was given that people adapt their verbal descriptions of objects depending on whom they expect would later use their descriptions (e.g., Dehler et al. 2007).

Second, in the field of social cognition, the knowledge imputing approach of Nickerson (1999) pointed out that communication partners need to have a reasonably accurate idea of what their communication partners know and do not know to be able to communicate effectively. Nickerson argues that not knowing what others know can lead to miscommunication and embarrassment. For example, overestimating the knowledge of one's communication partner may result in talking over his/her head, while underestimating the partner's knowledge may result in talking down to him/her. Both inhibit being able to communicate effectively. Further, without being able to communicate effectively, it is not possible to collaborate effectively (e.g., Clark and Brennan 1991).

Third, also in the field of social cognitive psychology, Wegner's theory of transactive memory system (Wegner 1986, 1995) highlights the importance of knowing what others know. A transactive memory system provides a group with information about where in the group, that is, in which individual memory, specific knowledge is stored. However, it is more than that: A transactive memory system is defined as "a set of individual memory systems in combination with the communication that takes place between individuals" (Wegner 1986, p. 186). Much empirical evidence exists showing that an efficient transactive memory system results in an increased group performance (e.g., Liang et al. 1995).

To sum up, knowing about the others' knowledge does not only result in a behavioural change, it also improves communication and collaboration and, as a result, group performance. Therefore, it is important to know what others really know. However, as described in the next section, it is difficult to develop an accurate idea of the knowledge of others.

Problems inherent in the development of knowing what others know

The difficulty of developing knowledge about the partners' knowledge arises from the processes for developing such knowledge: Nickerson (1999) highlights that, in the first step for generating knowledge about others' knowledge, "one uses one's own knowledge as the primary basis for developing [an idea of what others know]" (p. 737). This may work in

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some situations, but it "often results in imputing to others knowledge that they do not have" (p. 737). Therefore, people often overestimate the probability that another knows something that one knows oneself (e.g., Fussell and Krauss 1991; Keysar et al. 1995).

In addition, Nickerson (1999) points out that in the next step, people adapt their idea about the knowledge of others as a consequence of interacting with them, provided there is the possibility for interacting. Different types of cues are used in this process, particularly behavioural or categorical information (Krauss and Fussell 1991): For example, one can observe the behaviour of her/his partners; one can also directly pose questions to the others by asking "do you know anything about ..." questions, or one can also evaluate the category membership of others in order to develop a model regarding the knowledge of others (Nickerson 1999).

However, within all these mentioned possibilities, mistakes in judgment may happen: One can infer wrongly from what one saw, heard, or evaluated (cf. Nickerson 1999, for a detailed description of possible misjudgments). We would like to add that the opportunity to perceive and interpret such cues is not always available or at least strongly reduced, especially in CSCL settings.

Further, according to the transactive memory system approach of Wegner (1986), groups need a sufficient period of time to get to know each other in order to establish an effective transactive memory system.

To sum up, the problems associated with generating an idea of others' knowledge are that the group members tend to overestimate the similarity of "oneself" and others—that is, they tend to impute their own knowledge to others, and they also may misjudge perceived cues. They also need a sufficient period of time for interaction in their group.

Due to both the need for being informed about the other group members' knowledge and the problems in developing an accurate idea of others' knowledge, it is important to support these members in developing it. The development of such an accurate idea is much more difficult for newly formed groups in which the group members are unknown to each other. As an example, this could be experts brought together to solve a problem, having to start solving the problem directly and, therefore, not having time to get to know each other and to establish a transactive memory system. In this case, there is a high risk that they will misjudge their group members' knowledge, resulting in poor group performance. However, it could become even more difficult; namely, if the experts who are unknown to each other are not able to meet face-to-face, but instead have to collaborate and solve the problem on a computer-mediated basis. They are additionally confronted with the problems of groups collaborating computer-supported, in which the cues for developing a model of others' knowledge are highly restricted.

In the next section, a solution for this problem is presented that supports such virtual groups to improve collaboration and, therefore, their group performance by supplementing the missing knowledge about the knowledge of others.

Providing access to the others' knowledge and information

As described in group situations, there is a need to be informed about the knowledge of the collaboration partners. However, being informed about others' knowledge is not enough. As some authors state, it is also increasingly important to know where to find the required information (e.g., Siemens 2005; Tergan 2005). In this context, it is important to differentiate between the terms *knowledge* and *information*: We refer to the term *information* to describe contents outside of the cognitive system of a person. It is

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something to which the individuals have potential access, but is yet unknown. For example, a person would like to read a new book. This book is regarded to be information for her because she does not know the contents of the book; however, she has access to this book. After she has read this book intensively, she knows the content of the book, that is, she has the content cognitively processed. From this book, she could gain knowledge. Therefore, we refer to the term *knowledge* to describe something inside the cognitive system of a person. Knowledge is the content that is already cognitively processed and imbedded in the existing mental knowledge structures of a person (cf. Keller and Tergan 2005). In our opinion, it is important to know not only what knowledge other individuals have, but also from which information they have acquired their knowledge, in order to be able to evaluate the quality of this knowledge or to acquire one's own knowledge independently.

Therefore, the focus of our research is on fostering one's knowledge about both the others' knowledge and the others' access to information which they have used to acquire their own knowledge. For example, we inform Mary that Betty has knowledge about a specific fertilizer, but also that Betty has access to information, for instance, in the form of a link on the Web describing this type of fertilizer in detail. We call this type of knowing about others' knowledge—and information underlying this knowledge—*"knowledge and information awareness"* (e.g., Engelmann et al. 2010).

The construct *knowledge and information awareness* may be classified in the superordinate category of group awareness which is defined as "consciousness and information of various aspects of the group and its members" (Gross et al. 2005, p. 327). Instead of providing group members with direct instructions (e.g., collaboration scripts), group awareness approaches provide group members with relevant information about their collaborators, the collaborators' activity, the situation, or specific processes and occurrences in the group (Gutwin and Greenberg 2002). In the case of a knowledge and information awareness approach, the group members are informed regarding the others' knowledge *and* information underlying this knowledge.

In the study described in this paper, knowledge and information awareness is fostered by means of a particular tool which is operationalized by means of digital concept maps. Concept maps, developed by Joseph D. Novak (e.g., Novak and Gowin 1984), are a type of knowledge visualization for representing the knowledge of an individual by means of nodes, displaying concepts and labelled links between the nodes, representing the relations between the concepts. Traditional concept maps only visualize abstract conceptual knowledge, that is, the concepts and the relations between them, leaving out the information underlying the concepts (e.g., Tergan et al. 2006). By contrast, advanced digital concept mapping tools—like CmapTools (see http://cmap.ihmc.us/—provide) added functionality that allows direct access to sources of information. For example, if users do not understand a specific concept in a digital concept map, they can access the information which describes this concept in more detail by mouse clicking on this concept. Therefore, this digital concept mapping tool is especially well-suited to foster knowledge and information awareness; this has been already shown in the empirical study by Engelmann et al. (2010) for simulated virtual groups.

Empirical study

The goals of the empirical study presented in this paper are first to show that being provided with the collaboration partners' concept maps containing their knowledge structures and underlying information resources fosters knowledge and information awareness. This should replicate the findings of the study by Engelmann et al. (2010).

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(Note, however, that here we have "real" virtual groups, rather than simulated virtual groups in which the group members were only separated by partition walls and, therefore, could not see each other but could hear each other.) Second, the study should provide evidence that using such concept maps of the collaborators improves collaboration. Third, by means of this study, it should be shown that improved collaboration will positively influence collaborative problem solving.

Method

According to the design of the experimental study, two conditions are compared (see Table 1): In the control condition, the group members could only see a shared working window and one's own individual concept map containing one's own knowledge structures and underlying information. In an experimental condition, the group members were additionally provided with the individual digital concept maps of each of their collaborators.

Participants Participants were 120 university students (82 female, 38 male) from different fields of study having an average age of 23.48 years (SD=4.33). They volunteered to participate for either payment or course credit. The participants were randomly assigned to either the experimental condition or to the control condition. Each group consisted of three participants, resulting in 20 control groups and 20 experimental groups. The group compositions regarding gender were equal between the two conditions: In each condition, we had six groups consisting of three women, ten groups consisting of two women and one man, three groups consisting of one woman and two men, and one group consisting of three men. The degree of acquaintance between the group members was controlled by questionnaire items asking the group members whether they knew one or both of the collaborators. There was no significant difference between the conditions regarding the degree of acquaintance (M_C=0.75; M_E=1.25; $F(1,38)=1.92$; MSE=1.30; $p>.05$). In addition, the degree of acquaintance did not have an effect on the dependent measures (all Fs<1).

Materials and procedure Each group member of a triad was sitting in a separate room. Each of the rooms was equipped with a desk and a computer. In the collaborative phase of the study, the students could communicate with each other by using Skype, a free Web-based Internet phone software. The experimental environment was realized by using the software CmapTools. The experiment took place in German. Therefore, for this paper, all materials that were used in the study have been translated.

The students were required to work in a synchronous fashion with net-based, shared, and unshared desktop working windows. The experimental environment used in this study provided information elements that are necessary for rescuing a fictitious kind of spruce forest. These information elements consisted of 13 concepts, 30 relations between these concepts, and 13 (task irrelevant) pieces of background information (in parts divisible into sub-elements) (see Fig. 1).

Table 1 Design of the experimental study

Independent measures	Experimental condition: With access to the digital concept maps of the knowledge structures and information resources of the others	Control condition: Without access to the digital concept maps of the knowledge structures and information resources of the others
Number of triads	20 triads	20 triads

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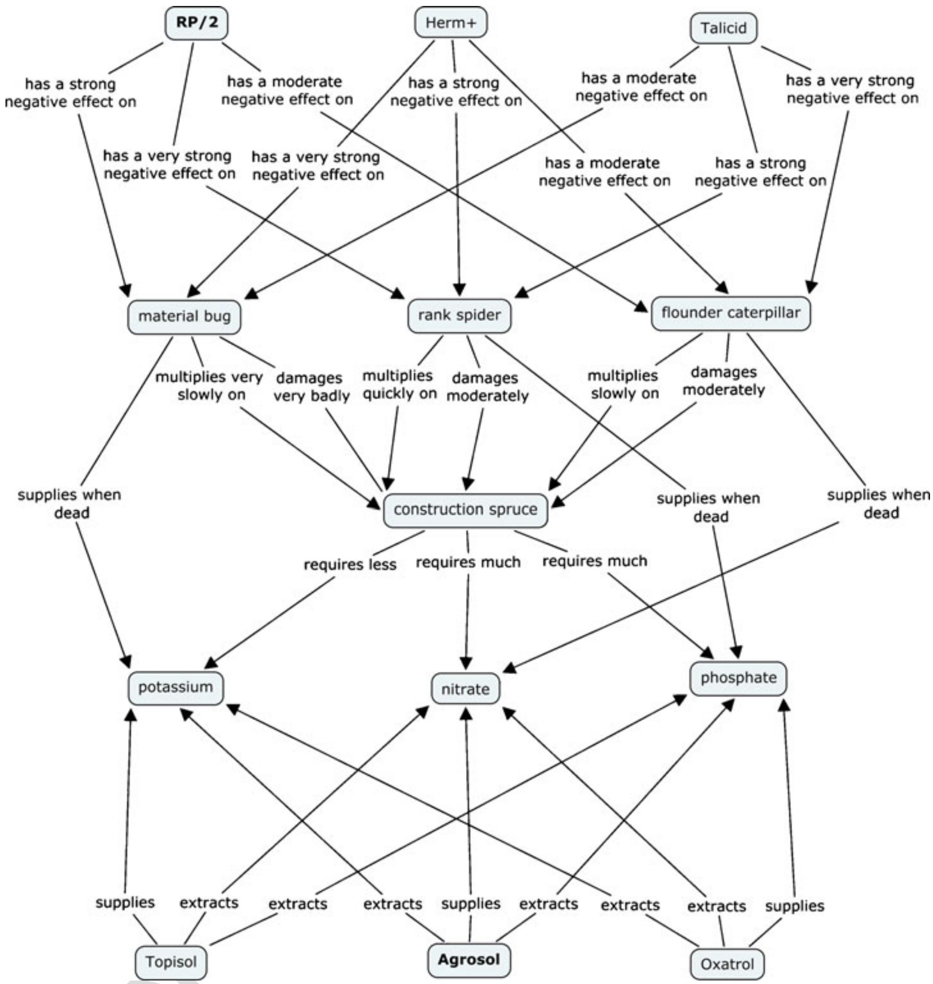

Fig. 1 Overview of the information elements used for the group task

These information elements were evenly distributed among the three group members: Each group member was provided with an individual concept map containing two unshared concepts, five shared concepts (with one or both other participant(s)), seven unshared relations, and six shared relations (with one other participant) (see Fig. 2). In addition, each participant was provided with two shared (with one other participant) and five unshared pieces of background information.

The procedure (see Table 2): At the beginning of the study, the participants were asked to complete an online questionnaire (25 multiple-choice items designed as five-point rating scales ranging from complete agreement to no agreement) aimed at *assessing control variables*, such as experience with computers (item-example: “I often use the computer”), mapping techniques (item-example: “I know what a concept map is”), and group work (item-example: “I often work together with others”).

Following the online questionnaire, they received an *introduction* to—and practiced using—*CmapTools*. After ensuring that all participants could use CmapTools without

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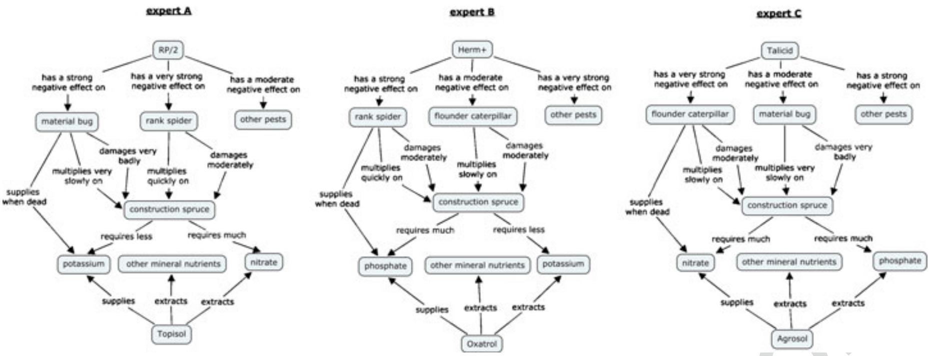

Fig. 2 Distribution of the information elements among the three group members

difficulty, they then started with *individual phase 1* of the experiment. At the outset of this phase, the group members were informed about the main task of the study by reading a handout: They were told that, for purposes of the experiment, they were three experts (expert a, b, and c) who have to collaborate in order to protect a spruce forest. They were further told that they should imagine that they had created a concept map containing her/his own knowledge and information a long time ago and, therefore, had to review their domain expertise for being prepared for the following collaborative task. To review their domain expertise, each group member was provided with a pre-created individual concept map

t2.1 **Table 2** Procedure of the experimental study

		Control condition	Experimental condition
t2.2		Control condition	Experimental condition
t2.3	Pre-phase: individual	Assessing control variables	Assessing control variables
t2.4		Practicing using CmapTools	Practicing using CmapTools
t2.5	Main phase: individual	Introduction to the tasks	Introduction to the tasks
t2.6		"Reviewing" (i.e. viewing) one's own concept map (10 min)	"Reviewing" (i.e. viewing) one's own concept map (10 min)
t2.7		Further 5 min for **"reviewing" one's own map**	**Additionally viewing one's own map, viewing the maps of the others** (5 min)
t2.8		"Manipulation check 1" to measure the amount of knowledge acquired from one's own map	**Manipulation check** 1 to measure the amount of knowledge acquired from one's own map and **the maps of others**
t2.9	Main phase: collaborative	Collaborative problem-solving: Each group member had access to one's own concept map and to the shared working window for creating a group concept map.	Collaborative problem-solving: Each group member had access to one's own concept map and to the shared working window for creating a group concept map, **but also to the individual concept maps of the others**.
t2.10	Post-phase: individual	Manipulation check 2: knowledge test to measure the acquired knowledge from the maps	Manipulation check 2: knowledge test to measure the acquired knowledge from the maps
t2.11		Assessing evaluative data	Assessing evaluative data

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containing the conceptual knowledge (i.e., concepts and relations) and background information (underlying the conceptual knowledge). Each of the three experts of a group had his/her own map, containing shared and unshared pieces of knowledge and information (see Fig. 2). The group members did not receive any additional material on the domain. The group members had 10 min for viewing their individual map.

In the *individual phase 2*, each participant in the control condition had 5 min to examine his/her own map again (see Fig. 3, left side). Each participant in the experimental condition, however, had 5 min to view his/her own map, as well as the maps of his/her collaborators (see Fig. 3, right side).

After this activity, all participants were asked to fill out individually a paper and pencil questionnaire used as a *manipulation check*. This questionnaire, having 15 multiple-choice items, measured the amount of knowledge that the participants had acquired from the map (s) (i.e., for the experimental condition from both their own map and the maps of the other group members, and, for the control condition only from their own map). Examples of items are: “Please mark which expert(s) had information about the fidget-grub—Expert A, B, or C?” or “Please mark which expert(s) had information about the fertilizer that yields nitrate—Expert A,B, or C?”.

Subsequently, the *collaborative phase* started: The three group members had to collaborate to solve two problems—namely, which pesticide and which fertilizer they would use to protect and to cultivate the spruce forest. They had to start with the pesticide problem. To solve this problem, the three experts had to compile their knowledge and information resources regarding reproduction and dangerousness of different pests and had to specify which pests they must exterminate most aggressively in order to be able to choose the correct pesticide. Only if the correct pesticide was chosen, the fertilizer problem

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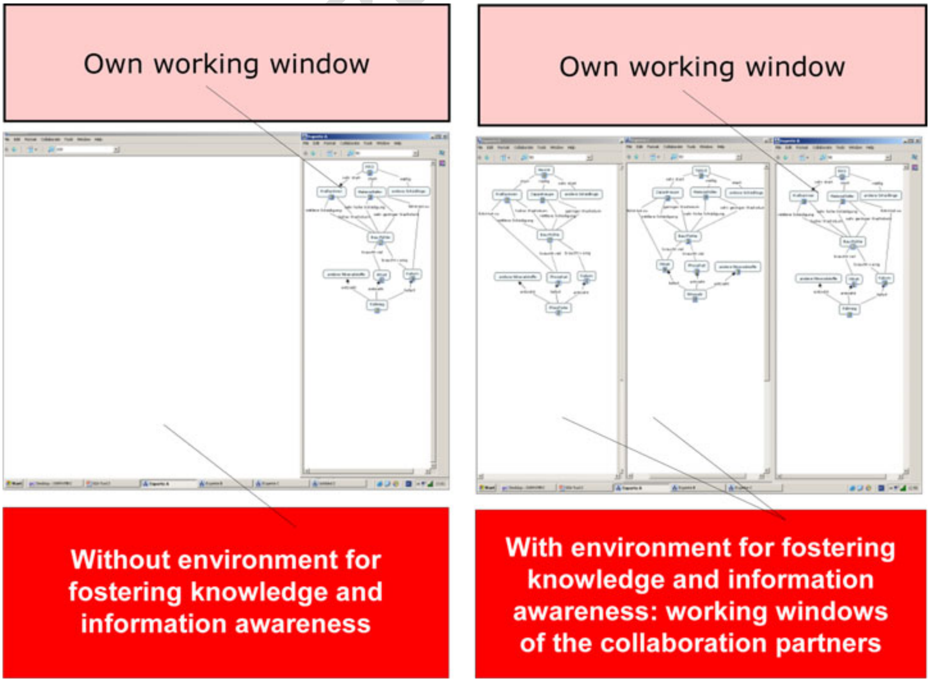

Fig. 3 Individual phase 2 (left: control condition; right: experimental condition)

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could be correctly solved; that is, the fertilizer problem was based on the pesticide problem. In order to solve the second problem, the experts needed to compile their knowledge and information regarding the mineral nutrients required in the soil. The solution of the pesticide problem influenced this decision because the different pesticides had different effects on the soil. The experts were told that there was only one possible correct solution for each problem. To compile their knowledge and information, the group members used a shared working window to create a mutual digital concept map containing the knowledge and information they were provided in the individual phase. In addition to the creation of a group map, the groups were asked to write on a sheet of paper their common solutions to the two problems and the reasons why they chose their solutions. They were instructed that one of the three experts should do this, in order to assure that they had negotiated common solutions. The participants had 40 min for collaboration. During this phase, they could speak with each other by using Skype. In the control condition, the participants could only see their own working window and the shared working window (see Fig. 4). In the experimental condition, the participants also saw the individual maps of their collaborators (see Fig. 4). In this collaboration phase, creating group maps and communication were recorded by using Camtasia. Also log files of the creation of group maps were recorded.

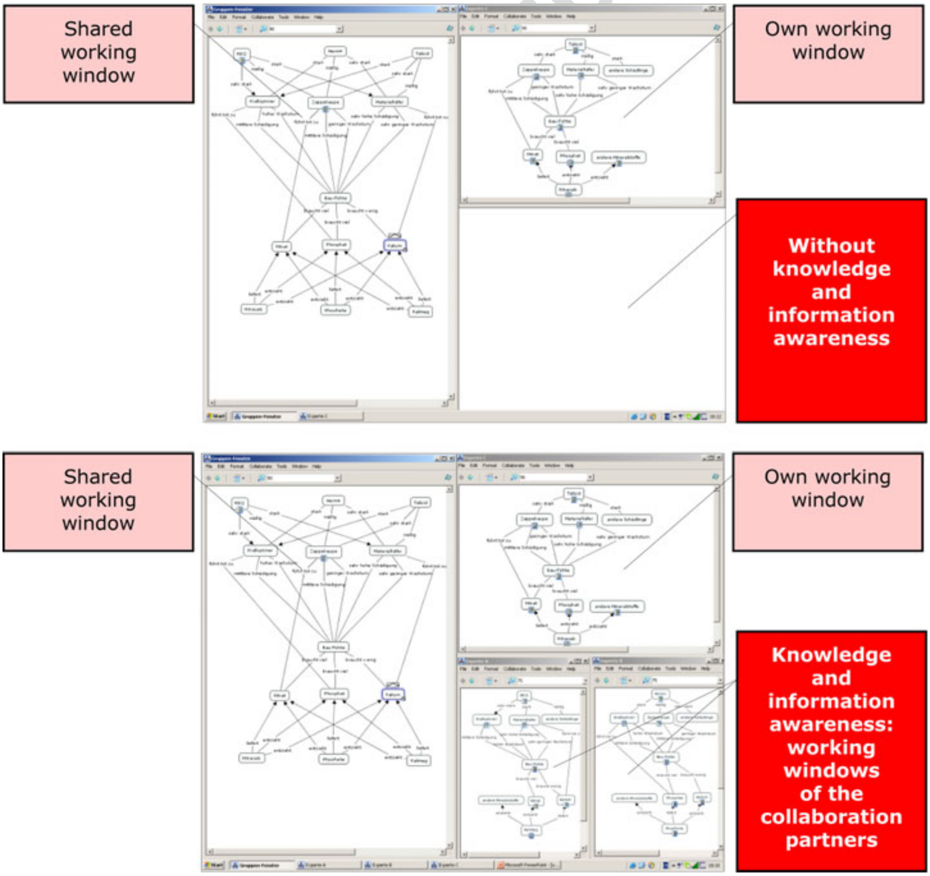

Fig. 4 Collaborative phase (above: control condition; below: experimental condition)

After this collaborative phase, again an individual phase began: First the participants were given another *knowledge test* to measure, among others, their knowledge regarding the knowledge structures and information resources of their group partners. In this test phase containing 36 multiple-choice test items, the experimental environment was no longer available. There were no time limits on this test. The items were of a similar type as the items of the manipulation check, but not identical. An item example is: "Please mark which expert(s) had information about the relation between RP/2 and the fidget-grub—Expert A, B, or C?"

At the end of the study, participants filled out a *questionnaire* assessing by five-point rating scales ranging from complete agreement to no agreement, for example, aspects of collaboration (item example: "I had the feeling that we worked together at the task"), communication (item example: "The others responded to my comments"), and coordination (item example: "Our coordination improved in the course of time"), as well as the use of CmapTools (item example: "I had difficulties in drawing relations"), and the helpfulness of seeing the individual digital concept maps with the knowledge structures and the information resources of the others (item example: "Seeing the individual maps of the others was helpful"). The questionnaire contained 57 items in the control condition; due to some additional items referring to the usefulness of seeing the others' concept maps containing their knowledge and information, there were 63 items in the experimental condition.

Expectations

As already explained, knowing what others know—and to which information they have access—should improve collaboration and, as a result, group performance. In the current study, individual concept maps representing the knowledge structures and underlying information resources of the collaborators were offered for acquiring knowledge about what the others know and to which information they have access.

Postulated effect on collaboration Because the members of the control condition were not provided with the individual concept maps of their partners (i.e., they had no direct access to the knowledge and its underlying information of their collaboration partners), it was suspected that they first would start to collect as much information as possible before they would begin with problem solving. In contrast, the members of the experimental groups had direct access to the others' knowledge and information and, therefore, information collecting would not be as important as in the control groups. Thus, it was expected that the experimental groups would start earlier with the problem-solving process compared to the control groups and, as a result, would be finished earlier with the problem-solving process.

Postulated effect on group maps In this study, it was not only expected that the groups in the experimental condition would be faster regarding the different problem-solving phases but furthermore, it was expected that they would create group maps that are more problem-oriented, that is, maps that only contain problem-relevant aspects leaving out irrelevant information.

Postulated effect on problem solutions It is expected that group maps containing only the task-relevant information—and therefore being more suited for problem solving—would improve collaborative problem-solving performance.

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Dependent measures

The following dependent measures were assessed:

Time differences regarding collaborative problem-solving activities In order to assess the collaboration processes, the video and audio files were recorded and analyzed with regard to the start time and end time (in seconds) of collaborative problem-solving activities. Ten different measurements are differentiated: (1) the start of creating the first part of the map for solving the pesticide problem (i.e., the time when the first node of the first map part is drawn), (2) the end of this activity (i.e., the time when the last node or relation of the first map part is drawn, compared to the end version of the map of the group), (3 and 4) starting and ending time of creating the second map part for solving the fertilizer problem, (5 and 6) starting to discussing both the pesticide and the fertilizer problem (i.e., the time when the group explicitly stated that they now are starting to discuss the first or the second problem—this the most groups did—or when they start to discuss without such an explicit statement), (7 and 8) the first time the correct answer to the pesticide problem and to the fertilizer problem is mentioned (e.g., when a group member said "In my opinion, RP/2 is the correct solution, because..."), and (9 and 10) writing down the solution to the pesticide and the fertilizer problem (i.e., ending time of both solving the pesticide problem and solving the fertilizer problem). Because only one group member was supposed to write the required information on the sheet of paper, they had to decide who would do this. Therefore, it was easy to measure the time when they started to write.

In addition, we analyzed whether the groups between the conditions differ regarding whether they started collaborating by collecting information or not. If the groups started their collaboration by verbally collecting information, the number 1 was assigned to them, if not they received the number 0.

The quality of the mutually created concept map In order to analyze the quality of the mutually created maps, the group maps were compared to the origin map (see Fig. 1), containing all concepts, relations, and background information. Five dependent variables were assessed: the number of correctly drawn nodes, that is, nodes with correct labels (max. 13 attainable points), the number of correctly drawn relations, that is, start and end node of the relation as well as the label were correct (max. 30 attainable points), the number of incorrectly drawn nodes, these are nodes with wrong labels (attainable points: not limited), the number of incorrectly drawn relations, that is, start and/or end node and/or the label were wrong (attainable points: not limited), the amount of (irrelevant) background information (max. 13 attainable points). The groups received one point for each entry of each category (e.g., if the map of group xy contained 10 correct nodes, the group xy received 10 points for the category "correctly drawn nodes").

The quality of the group answers to the two problem-solving tasks In this context, it was differentiated between the correctness of a solution and the correctness of the reasons given for a correct solution. There was only one possible correct solution for the two problems. For each correct solution, one point was given. Only if the correct solution was found, were the reasons given then analyzed according to an analyzing schema with 0 points for a completely wrong answer and up to three points for a completely correct answer. In order to determine the correctness of the reasons given, they were compared to the original correct reasons. For each problem, there was only one line of argument. Whenever the solution was

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wrong, 0 points were given for the reasons. Two psychologists who were familiar with this study material, but who were blind regarding which condition the data belonged to, acted as independent raters and analyzed the reasons given by the groups. The inter-rater agreements were calculated: Regarding the reasons given as to why they chose the correct pesticide, Cohen's kappa was κ=0.97 (cf. Cohen 1960). With regard to the reasons given as to why they chose the correct fertilizer, Cohen's kappa for inter-rater agreement was κ=0.96.

Questionnaire data In addition, for corroborating the findings regarding the research questions, subjective data were assessed by means of five-point rating scales in a questionnaire in order to determine, for example, aspects of communication and coordination and the use of CmapTools.

Results

The analysis was based on a statistical comparison of the experimental and the control condition. All analyses presented here are based on the 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, because the individuals in a group were not independent of each other. With regard to the 25 control measure items (e.g., experience in group work), a factor analysis with Varimax rotation was conducted, resulting in seven factors with eigenvalues higher than 1. According to Bortz (1999), in a Varimax-rotated factor structure only such factors are interpretable that have at least four items with a loading >.60 or at least ten items with a loading >.40. This criterion was met only by the first three factors. The factors were Experience with Computers, Experience with Collaborative Problem Solving, and Experience with Mind Maps. For each of these factors, a univariate ANOVA was performed, showing that there were no significant differences between the two conditions. Therefore, the inclusion of a covariate was not necessary.

As a descriptive index of strength of association between the experimental factor and a dependent variable, partial eta-squared values (η_p^2) are reported[1] (Pierce et al. 2004).

Manipulation check

The objective of the manipulation check was to determine whether having access to the individual concept maps of the collaboration partners fosters knowledge and information awareness, that is, fosters knowledge of the knowledge structures and underlying information resources of the collaboration partners. According to the results of the study by Engelmann et al. (2010), it can be assumed that the availability of such individual concept maps leads to more knowledge and information awareness.

The *manipulation check* included two types of measurements: First, the *knowledge and information awareness test after the individual phase 2* consisted of 15 multiple-choice items. This test measured among others whether the groups in the experimental condition

[1] Partial eta-squared value of an experimental factor is defined as "the proportion of total variance attributable to the factor, partialling out (excluding) other factors from the total nonerror variation" (Pierce et al. 2004, p. 918). Due to the fact that classical eta-squared values for an effect are dependent upon the number and the magnitude of other effects, partial eta-squared values are preferred in this paper (Cohen 1973).

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had already acquired knowledge and information awareness after the individual phase 2 by asking who of the others possessed specific knowledge and information (max. 30 attainable points).

With regard to this test, the groups in the experimental condition achieved on average 22.12 points (SD=2.24), that is, 73.73% of the overall score. Therefore, the analysis showed that, after the individual phase 2, the participants in the experimental condition had already acquired a certain amount of knowledge and information awareness. The participants of the control condition also filled in the test in order to assure the same procedure phases for both conditions. However, this test was a measurement taken after the individual phases; therefore, at that time, the participants of the control condition could not have acquired knowledge and information awareness yet. They could only answer items referring to aspects in their own map. Therefore, it was not necessary to analyze their data as a manipulation check.

Second, the *knowledge test after the collaborative phase* consisted of 36 multiple-choice items. These items were classified with regard to who possessed the requested knowledge or information. There were four types of items:

(1) Items asking for knowledge elements or information that only oneself had in his/her individual map, that is, one's own unshared elements. (Item example for expert A: "Please mark which expert(s) had information about the relation between RP/2 and fidget-grub—Expert A, B, or C?" Only expert A had this information.).
(2) Items asking for knowledge elements or information that only one of the collaborators had, that is, the unshared elements of each collaborator. (Item example for expert A: "Please mark which expert(s) had information about the relation between Agrosol and phosphate—Expert A, B, or C?" Only expert C had this information.).
(3) Items asking for knowledge elements that oneself and one of the collaborators had, that is, the shared elements that one shared with one of the collaborators. (Item example of expert A: "Please mark which expert(s) had information about the relation between spruce and nitrate—Expert A, B, or C?" Only experts A and C had this information.).
(4) Items asking for knowledge elements that only both collaborators had, that is, shared elements of the collaborators. (Item example of expert A: "Please mark which expert (s) had information about the relation between spruce and phosphate—Expert A, B, or C?" Only experts B and C had this information.).

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For the manipulation check, the types of items from categories 2 and 4 are especially interesting, assessing the acquired knowledge about the knowledge of the others. For each correct solution, one point was given.

As expected, the analysis of this *knowledge test after the collaborative phase* revealed—regarding the item category 4—a better performance for the experimental groups(M_E=6.22) as compared to the control groups (M_C=5.13) regarding knowledge about information that only the two other experts had (F(1,38)=5.43; MSE=2.21; p<.05; η_p^2=.13) (max. 9 attainable points). However, in contrast to our expectation, no significant difference regarding the unshared elements of each collaborator—that is, item category 2—was found (F<1). It is interesting to note that compared to the experimental groups, the groups in the control condition achieved a higher performance for knowledge of information than only the individual expert (oneself) possessed (M_C=5.28; M_E=4.66; F(1,38)=5.22; MSE=0.73; p<.05; η_p^2=.12) (max. 7 attainable points) (item category 1). Regarding items on elements that one shares with one of the collaborators (item category 3), no significant difference occurred(F<1).

The results of both manipulation checks confirmed to a large extent our expectation that the environment applied fosters knowledge and information awareness.

Results of collaboration processes

In order to test the expectation postulating that the experimental groups start earlier with problem-solving processes compared to the groups in the control condition, the video and audio files were analyzed. The results of the analysis confirm this hypothesis: The experimental groups started significantly earlier, both in discussing the first problem on pesticides (M_C=727.4 sec.; M_E=232.1 sec.; $F(1,38)=11.53$; MSE= 212886.44; $p<.01$; $\eta_p^2=.23$), as well as in discussing the follow-up problem on fertilizers (M_C=1421.3 sec.; M_E=864.9 sec.; $F(1,38)=15.73$; MSE=196890.28; $p<.01$; $\eta_p^2=.29$). In addition, the experimental groups ended significantly sooner, both in drawing the first part of the map regarding the pesticide problem(M_C=1204.0 sec.; M_E=782.4 sec.; $F(1,38)=11.09$; MSE=156096.58; $p<.01$; $\eta_p^2=.23$), as well as in drawing the second part of the map to solve the fertilizer problem (M_C=1499.7 sec.; M_E=1130.4 sec.; $F(1,38)$= 9.66; MSE=141093.25; $p<.01$; $\eta_p^2=.20$). Furthermore, the experimental condition solved the fertilizer problem significantly faster compared to the control condition (M_C= 1561.4 sec.; M_E=1211.3 sec.; $F(1,38)=5.18$; MSE=112174.25; $p<.05$; $\eta_p^2=.23$). Figure 5 presents a diagram showing the time differences between the two conditions with regard to starting or ending problem-solving activities.

The expectation is also confirmed by the results that, at the beginning of the collaborative phase, only in the control condition was verbal information collected, but not in the experimental condition (M_C=0.7 sec.; M_E=0.0 sec.; $F(1,38)=44.33$; MSE=.11; $p<. 01$; $\eta_p^2=.54$).

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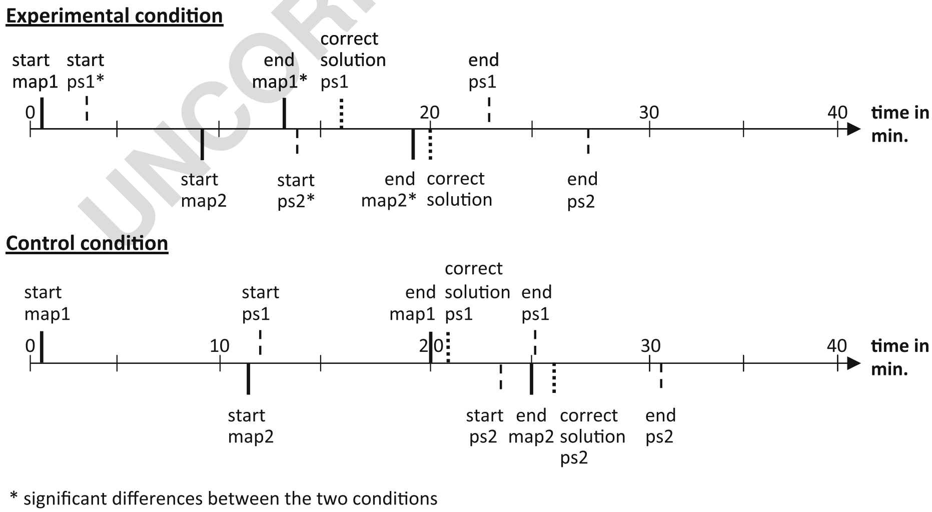

Fig. 5 Time distribution of problem-solving activities in the experimental and the control condition. (start map1 / end map1: start / end of creating the first map part for solving the pesticide problem; start map2 / end map2: start / end of creating the second map part for solving the fertilizer problem; start ps1 / end ps1: start to discussing / writing down the solution to the pesticide problem; start ps2 / end ps2: start to discussing / writing down the solution to the fertilizer problem; correct solution1 / correct solution2: first time the correct answer to the pesticide problem / fertilizer problem is mentioned)

Results of group concept maps

Regarding the *group maps*, the control groups drew more correct relations (M_C=23.3; M_E= 19.5; $F(1,38)=6.42$; $MSE=23.72$; $p<.05$; $\eta_p{}^2=.19$) as compared to the experimental condition. However, there were no significant differences between the conditions with regard to incorrectly drawn relations (M_C=2.2; M_E=1.3; $F(1,38)=1.18$; $MSE=6.85$; $p=.28$) or concepts ($F<1$). In addition, the groups in the control condition included more irrelevant background information (M_C=8.6; M_E=4.6; $F(1,38)=10.12$; $MSE=16.02$; $p<.01$; $\eta_p{}^2=.21$).

Results of problem-solving tasks

The analysis of the *problem-solving tasks* showed no significant differences between the conditions regarding the number of correct answers to the pesticide problem (M_C=0.7; M_E=0.9; $F(1,38)$ = 1.27; $MSE=0.18$; $p=.27$) and with regard to the reasons given as to why they chose the correct pesticide (M_C=1.4; M_E=2.1; $F(1,38)=3.29$; $MSE=1.49$; $p=.08$; $\eta_p{}^2=.08$).

By contrast, regarding the number of correct answers to the fertilizer problem (M_C=0.55; M_E=0.95; $F(1,38)=10.31$; $MSE=0.16$; $p<.01$; $\eta_p{}^2=.21$), as well as regarding the reasons given as to why they chose the correct fertilizer (M_C=0.85; M_E=2.1; $F(1,38)=22.53$; $MSE=0.69$; $p<.01$; $\eta_p{}^2=.37$), the experimental condition attained a significantly higher performance compared to the control condition.

Results of questionnaire data

With regard to the 57 questionnaire items that were answered by participants of both conditions at the end of the study, three factor analyses with Varimax rotation were necessary in order to conform to the factor analyses requirement regarding the ratio between the number of items and the number of cases.

In the first factor analysis, all items on the general evaluation of the study, the use of CmapTools, and the group performance were included (23 items). This resulted in eight factors with eigenvalue >1. However, only one factor had at least four items with loadings over >.60 and, therefore, was interpretable (cf. Bortz 1999). This factor was named "General Estimation of the Group Performance." However, an ANOVA did not result in a significant difference between the conditions regarding this factor ($F<1$).

In a second factor analysis, all items evaluating the teamwork in general and its helpfulness as well as items evaluating the communication were included (18 items). The analysis revealed, according to Bortz (1999), only two interpretable factors, namely, the factor "Liking the Team Work" and the factor "Helpfulness of Teamwork for Acquiring a Domain Content Overview." For each factor, a univariate ANOVA was performed. However, only for the second factor could a significant difference be found: For the groups in the control condition, the teamwork was more helpful for identifying information gaps, for acquiring an overview of the information, and for understanding the relations between information elements, compared to the groups in the experimental condition (M_C= 0.6; M_E=–0.6; $F(1,38)=23.71$; $MSE=0.98$; $p<.01$; $\eta_p{}^2=.38$).

A third factor analysis with 16 items on coordination and group atmosphere resulted, according to Bortz (1999), in one interpretable factor named "Fostering and Maintenance a Positive Group Atmosphere." An ANOVA showed a significant difference between the conditions: The groups in the experimental conditions evaluated the group atmosphere more positively and tried more strongly to foster a positive group atmosphere compared to

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the groups of the control condition (M_C=−0.3; M_E=0.3; F(1,38)=5.05; MSE=0.91; p<.05; η_p^2=.12).

The results of the six items that were only answered by participants of the experimental conditions may only be reported descriptively. These data show that the experimental groups, by marking a five-point rating scale with the number one for "no agreement" and the number five for "complete agreement," evaluated the others' maps for fostering knowledge and information awareness as useful (M_E=4.4; SD_E=0.4), as essential (M_E=3.8; SD_E=0.6), and as helpful (1) for acquiring a clear idea of the others' knowledge (M_E=4.3; SD_E=0.5), (2) for avoiding misunderstanding (M_E=4.2; SD_E=0.4), (3) for each other's understanding regarding the individual contents (M_E=4.3; SD_E=0.4), and (4) for recognizing the similarities and differences of the experts' knowledge (M_E=4.2; SD_E=0.7).

Discussion and conclusions

In this paper, the importance of enhancing knowledge and information awareness for newly formed groups whose members collaborate virtually by means of computer support is demonstrated. Knowledge and information awareness is defined as being aware of both the others' knowledge and the others' access to information upon which their knowledge is based (cf. Engelmann et al. 2010). Knowledge and information awareness was fostered by means of digital concept maps providing the conceptual knowledge of the collaboration partners, as well as the background information underlying this knowledge.

In the present study, an experimental condition, provided with digital concept maps representing the partners' knowledge and information, and a control condition, working without them, are compared. The results from the collaboration analysis showed, as expected, that the groups of the experimental condition started significantly earlier discussing both the pesticide problem and the fertilizer problem. They were also significantly faster in creating the pesticide map portion, as well as the fertilizer map portion, and further, they solved the fertilizer problem significantly sooner. In addition, the groups of the control condition often started their collaboration phase with collecting information, while not one group of the experimental groups did this.

These results provide evidence that the collaboration in the experimental condition is more efficient compared to the control condition and that the experimental groups did not have the need to collect information. By being provided with the external representations of all collaborators' knowledge and information, they had all the information they needed to start with the problem-solving process.

The analysis of the group concept maps provide evidence that the groups of the control condition used the group map mainly to collect all of the information they had in their individual maps. Therefore, they also included more problem-irrelevant information, such as background information, compared to the groups in the experimental condition. By contrast, the experimental groups seemed to include only such information in their maps that they evaluated as being helpful for problem solving. Assuming that the commonly created group map serves as an externalized group memory, the groups of the experimental condition had the advantage of having only the relevant information for solving their problems in their map, while the groups of the control condition still needed to pick out the relevant aspects.

These findings on group maps point to different strategies in map creation between the two conditions, namely, as expected, to a more problem-oriented map creation in the experimental groups. It seems that the groups in the two conditions differ regarding at what

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time they decide about the task-relevance of an aspect. While the groups of the control condition seem to make these decisions after their common map creation, the groups of the experimental condition seem to do this before their common map creation. It might be interesting in further studies or analyses to ask the groups in the different conditions directly about their goals during their group map creation and about the point in time when they evaluate the task-relevance of aspects.

The results from analyzing the problem-solving answers have to be interpreted by considering that the fertilizer problem is based on the pesticide problem, that is, the correctness of the fertilizer problem resolution depends on the correctness of the pesticide problem resolution. Only if the pesticide problem is solved correctly, is it possible to solve the fertilizer problem. The analyses showed that the conditions did not differ significantly regarding the solution to the pesticide problem, but the experimental groups significantly outperformed the control groups regarding the fertilizer problem. These results, partly confirming the expectation, might be a hint that fostering knowledge and information awareness is especially important for solving more difficult tasks.

The results of the evaluative data support the expectation that, in the groups in the control conditions, there is more need to work together with others in order to acquire knowledge about the others' knowledge and information. In the experimental condition, this knowledge could be acquired by viewing the others' digital concept maps. Other differences between the conditions were not found. This could be a confirmation that there are really no other differences between the conditions regarding communication and collaboration aspects or regarding the use of the software. However, another possible explanation could be that the questionnaire items did not measure the existing differences. Perhaps additional analyses of the video and audio files regarding communication and collaboration aspects could better reveal any existing differences.

The descriptive data showed that the opportunity to acquire such knowledge by means of these maps is evaluated as useful and helpful. Considering the aforementioned difficulties of acquiring correct knowledge about the others' knowledge in a normal way—that is, by evaluating others and by interaction with them—the approach applied in this study provides an easy way to foster knowledge about others' knowledge and to limit or even avoid mistakes while developing it.

To sum up, the expectations were to a large extent met, but have left some questions open that must be answered in further studies. It should be emphasized, however, that the results found in our study are by no means trivial: The participants in the experimental condition had to process the additional external representation of the other group members' knowledge and information. This imposes an additional cognitive load and may hinder working memory. However, as the results show, the additional effort does not impair the group performance. In contrast, the additional representations, that have to be processed, foster group performance.

In addition, this study has demonstrated that CSCL environments are not necessarily impoverished compared to face-to-face situations regarding contextual information, but can even provide information that is not available in a normal face-to face situation. Providing group members with digital concepts maps visualizing the collaborators' knowledge and underlying information is a good example of what is meant here. In a face-to-face situation, one would not be able to see the others' knowledge and underlying information. It is important to find out the relevant information aspects that CSCL environments need to include in order to allow a form of collaboration that is as

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effective as—or even more effective than—collaboration in normal face-to-face situations.

It was explained that to be able to communicate and collaborate efficiently, groups need correct knowledge about what the others know and that it is very difficult, especially in CSCL settings, to develop such knowledge. In this paper, a simple approach was suggested for fostering such knowledge by means of digital concept maps representing the knowledge structures and underlying information of the collaboration partners. The results of the empirical study show that this approach may be helpful for fostering collaboration and problem solving of groups in CSCL settings. Therefore, this approach frees groups from the need to spend a long time getting to know each other in order to develop naturally accurate knowledge about each others' knowledge. This approach is in contrast to the literature that highlights the necessity of lengthy common training phases for the group members in order to develop knowledge about what the others know as required for effective collaboration.

The approach presented in this paper is easy to apply in different settings and application fields: for example, for collaborating virtual groups in or between schools, universities, and organizations. However, some constraints must be considered: Not every domain is suited to being represented in a digital concept map. In addition, the amount of knowledge and information to be represented in concept maps is limited in order to provide a clear arrangement of the contents. Furthermore, the group size is limited in order to allow for an overview of all the maps of the partners. Further research could also investigate whether there are other possibilities for presenting knowledge and information representations that make it possible to apply this approach to larger groups or to larger amounts of knowledge and information. In this study, the participants were students and—because of empirical reasons—they had to solve problems with unique, well-defined solution paths. In contrast, real experts are often confronted with badly structured problems that do not have a clearly defined solution. Therefore, strictly speaking, this study explored the role of knowledge and information awareness in situations of computer-supported collaborative learning with students. The role of knowledge and information awareness in CSCL situations involving real experts will need to be investigated in further studies.

In the current study, the individual maps were pre-created and the participants were told that they should imagine that they created their maps a long time ago and now have to review them. In order to increase ecological validity, in further studies the participants should create their maps themselves. For applying our method used in this study to fostering knowledge and information awareness in application fields, it should be mentioned that it indeed requires effort by each group member to externalize their own knowledge and to structure it. However, this method does not just require additional effort, it also fosters metacognitive processes that may lead to more elaboration regarding one's own knowledge. Considering that a practical method was presented here for enabling newly formed virtual groups to collaborate efficiently, to improve their group performance, and—as a by-product—to foster their metacognitive processes, the results of this study are of high practical relevance.

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Q1. The citation 'Malone and Crowstone (1994)' (original) has been changed to 'Malone and Crowston (1994)'. Please check if appropriate.

Q2. 'Bortz (1999)' is cited in text but not given in the reference list. Please provide details in the list or delete the citation from the text.

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