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PROVIDING GROUP KNOWLEDGE AWARENESS IN COMPUTER-SUPPORTED COLLABORATIVE LEARNING: INSIGHTS INTO LEARNING MECHANISMS

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In collaboration, group knowledge awareness (i.e. being informed about the partners' knowledge) is used to effectively communicate and to efficiently coordinate interaction. Computer-mediated collaboration impairs the establishment of group knowledge awareness. Technological support for group knowledge awareness can compensate for this shortcoming and is realized in a group knowledge awareness tool that visualizes the collaborators' self-assessed knowledge. In an experimental study, we varied the availability of the group knowledge awareness tool and investigated the mechanisms of collaborative learning with and without the tool by adopting a contrasting cases approach. Comparing dyads selected for their notably low or high learning outcome in both experimental conditions revealed distinct learning mechanisms with and without the tool: more individual elaboration was found in high compared to low outcome dyads in the control condition, while more collaborative elaboration was found in high compared to low outcome dyads in the group knowledge awareness condition. Using the tool for coordination in dyads with large knowledge differences, that is distributing activities according to the knowledge difference, set high outcome dyads apart from low outcome dyads, when they were provided with the tool. Implications for the design and practical use of group knowledge awareness tools are discussed.

Keywords: Computer-supported collaborative learning (CSCL); group awareness; knowledge awareness; contrasting cases analysis.

1. Introduction

Computer-mediated collaboration has become widespread in educational practice: for example, in distributed teams or computer-supported collaborative learning (CSCL) in higher education. The degree of knowledge difference among group members ranges from rather equally distributed knowledge (e.g. collaborating students in a virtual doctoral school) to notably asymmetric knowledge (e.g. net-based expert-layperson communication). Collaborators can benefit from mutually knowing about other group members' knowledge and likewise knowing about knowledge differences within their group. We refer to being informed about the others' knowledge as group knowledge awareness (GKA).

1.1. *Group knowledge awareness in computer-mediated collaboration*

According to Nickerson (1999), GKA is achieved in a three-step process: first, one's own knowledge is taken as a basic estimation; second, information about the partners' characteristics (e.g. their profession, such as computer scientist) are used to deduce the partners' knowledge (Clark & Marshall, 1981) and to modify the basic estimation; third, interaction provides further evidence of the partners' knowledge (Clark & Brennan, 1991). Evidence of knowledge can either be given explicitly when deliberately informing partners about one's own knowledge or be inferred implicitly from a partner's behavior when, for example, the content of a contribution discloses the author's knowledge.

Technology-rich collaboration environments set specific conditions on establishing GKA as compared to face-to-face interaction (Kraut, Fussell, Brennan, & Siegel, 2002). Context cues are reduced such that less information about partner characteristics are available (Kiesler, Siegel, & McGuire, 1984). This is particularly problematic for newly composed groups or groups of changing composition where evidence of the partners' knowledge can only be accumulated with great difficulty. The costs associated with providing information about one's knowledge vary with the characteristics of media (Clark & Brennan, 1991). For example, turn-taking is cost-intensive in asynchronous communication, thereby impairing reactions and interactions on explicit evidence of GKA. Due to the lack of context cues, implicit evidence of knowledge can be highly ambiguous (Daft & Lengel, 1986), which reduces the possibility to infer information about others' knowledge (Kraut *et al.*, 2002). As less information for modifying the initial self-based estimation of others' knowledge is available in computer-mediated collaboration, GKA is expected to be systematically biased towards one's own knowledge (Nickerson, 1999). Due to this self-heuristic, groups with highly asymmetric knowledge are more biased in their GKA and their collaboration is thereby more impaired as compared to groups of symmetric knowledge (Sangin, Molinari, Nüssli, & Dillenbourg, 2008).

Biased or insufficient GKA can affect collaboration, particularly in terms of communication and coordination (Leinonen & Järvelä, 2006). Regarding communication, GKA can support both producers and recipients of contributions. It enables producers to adapt their contributions to the recipient's knowledge (e.g. what and how to explain to the partner). Such adaptation was captured by the notion of audience design (Clark & Murphy, 1982). Producers benefit from adaptations to the partner, because these adaptations can trigger knowledge transforming (Chan, Burtis, Scardamalia, & Bereiter, 1992). Recipients benefit from adapted contributions, because they can more easily understand and further elaborate the content (Webb & Palinscar, 1996). Research on expert-layperson communication, for example, found that learning by the lay recipient depends on knowledge awareness of the producing expert: with valid knowledge awareness, the expert's explanations were more helpful for layperson learning than they were with a lack of or false knowledge awareness (Nückles, Wittwer, & Renkl, 2005).

In terms of coordination, GKA affects how efficient collaboration can be organized. Efficient collaboration coordinates interdependent activities (Malone & Crowston, 1990). With adequate (i.e. not self-biased) GKA, collaborators know what activities are useful for the partner, can adjust their behavior accordingly, and can anticipate partner activities. GKA helps group members to coordinate their collaborative activities corresponding to their knowledge distribution. For example, Chi, Siler, and Jeong (2004) found that tutors need adequate awareness about their tutees, knowledge in order to engage in effective tutoring activities. Speaking about collaborative learning in general, in a group with highly asymmetric knowledge, for example, a less knowledgeable partner can react to GKA by seeking help and information from more knowledgeable partners. Conversely, a more knowledgeable partner can adapt to GKA by providing help and explanations to less knowledgeable partners (Sangin *et al.*, 2008). That is, groups with asymmetric knowledge can coordinate towards asymmetric activities. Groups with symmetric knowledge can coordinate towards symmetric activities, with all members providing as well as seeking help and information. Thus, GKA can help to adjust the asymmetry of activities according to the asymmetry of the knowledge distribution.

Taken together, computer mediation impairs the establishment of GKA towards a self-bias and inadequate GKA negatively affects collaboration. Therefore, providing support for GKA is expected to foster computer-mediated collaborative learning.

1.2. *A tool for support of group knowledge awareness*

In the field of computer-supported cooperative work, groupware was developed that enriches the cooperation environment with awareness of the partners' activities (Dourish & Belotti, 1992; Carroll, Neale, Isenhour, Rosson, & Crickard, 2003). In order to establish GKA with this groupware, learners have to infer their partners' knowledge from activity information. Recently, specific knowledge awareness tools have been suggested in the field of CSCL. These tools allow GKA to be inferred based on, for instance, the availability of learning content (Engelmann & Tergan, 2007) or based on knowledge test performance (Sangin, Nova, Molinari, & Dillenbourg, 2007). The type of awareness tool should be selected in order to best fit the requirements of a collaborative situation (e.g. as a function of task characteristics like division of labor vs. collaborative task). GKA tools are helpful in collaborative situations where activity awareness is not sufficient to interpret partner activities and to deduce adequate own activities. For example, being informed that the partner is reading a certain text paragraph does not imply information about why the partner does so (e.g. is the partner searching for information not yet understood or re-reading a sentence in order to prepare an explanation for someone else?) and which own activities could help the partner (e.g. should I explain to the partner?).

We designed a GKA tool in order to allow the easy insertion and interpretation of GKA information. The use of information in knowledge awareness tools is facilitated by providing comparable information about the partners' and the learner's own knowledge (Bratitsis & Dimitracopoulou, 2007). Existing tools do not provide specific support for comparability. For instance, Sangin *et al.* (2007) provide only information about the dyad partner's and not the learner's own knowledge; Engelmann & Tergan (2007) visualize knowledge with a rather complex concept mapping representation. Our tool was designed to provide comparable information about the learner's own knowledge, partner knowledge and, thereby, the distribution of knowledge. Input to the tool is given by the collaborators themselves as they subjectively self-assess their own knowledge. Self-assessed knowledge is then visualized in the tool.

Previous empirical work investigated this tool in a scenario of simulated collaboration (Dehler, Bodemer, & Buder, 2007) in order to study GKA-triggered audience design and its impact on learning. Information about the partners' knowledge was used to adapt communication (i.e. explanations in this particular case). For example, learners provided their partners with longer explanations containing more elaborations on topics of partner deficits than on topics of partner knowledge. Adaptations were found to be beneficial for constructing elaborated knowledge. This previous study mainly focused on effects of knowledge awareness on the production of explanations and thus was realized as simulated collaboration. In the current paper, a study is reported that sheds light on the effects of GKA on interactive collaboration. This allows aspects of collaboration that cannot be simulated (e.g. the coordination between group members) to be addressed. Our research questions are:

(RQ1) How do collaborative *learning activities* differ between groups with the GKA tool and groups without the tool?

(RQ2) How do the *learning mechanisms* (i.e. the learning activities that are positively associated with learning outcome) differ between groups with the GKA tool and groups without the tool?

Thus, the influence of a GKA tool on learning outcomes itself is not central to the current paper. Here, we focus on GKA tool influences learning activities and learning mechanisms (i.e. the relation between activities and learning outcome). In order to answer these research questions, we adopted a contrasting cases approach (Onwuegbuzie & Teddlie, 2003). Dyads were selected based on their learning outcome. Then, the collaborative learning activities of low and high learning outcome dyads were compared in both experimental conditions separately.

2. Method

2.1. *Design*

Participants were randomly assigned to two experimental conditions. In both conditions, participants learned first individually and then collaboratively. Conditions differed according to the awareness information provided during collaboration. In the control condition, only information about the participant's own knowledge was available. In the GKA condition, participants were provided with information about their group's knowledge, that is, about their own and their dyad partner's knowledge.

2.2. *Participants*

86 students from the University of Tuebingen participated in the experiment for payment. The average age was 24, ranging from 18 to 42 ($SD = 3.90$). Participants were all native German speakers. Unacquainted individuals were grouped in pairs. From a total of 43 dyads, we excluded five dyads because they did not follow the task instruction (in three dyads, one of the participants did not read the learning material; in one dyad, one of the participants waited for more than ten minutes to write a first contribution for the 30-minute communication task; and one dyad's participation, as indicated by number of contributions, was lower than two standard deviations below the mean). The remaining 38 dyads were equally distributed between the control and GKA condition, with 19 dyads each. Eight dyads were identified on the basis of their performance in the learning outcome measure. For both the control and GKA condition, dyads with the lowest and highest learning outcome were selected (for selection mode, see Sec. 3.2.).

2.3. *Learning environment*

The learning environment provided participants with different components depending on the phase of the experiment: learning material (individual and collaborative phase), knowledge awareness visualization (collaborative phase), and collaboration area (collaborative phase). Figure 1 displays the learning environment during collaboration.

2.3.1. *Learning material with integrated knowledge assessment*

Participants learned from hypertext on the immune system. Pages were multilinked to allow for flexible navigation. Each hypertext page was divided into five paragraphs. Paragraphs formed the unit of knowledge assessment necessary for the experimental variation. Participants self-assessed their own knowledge during individual learning. Alongside each text paragraph, a small box was displayed, whose color could be selected by clicking on the respective box. By instruction, participants were asked to subjectively evaluate for each paragraph whether or not their

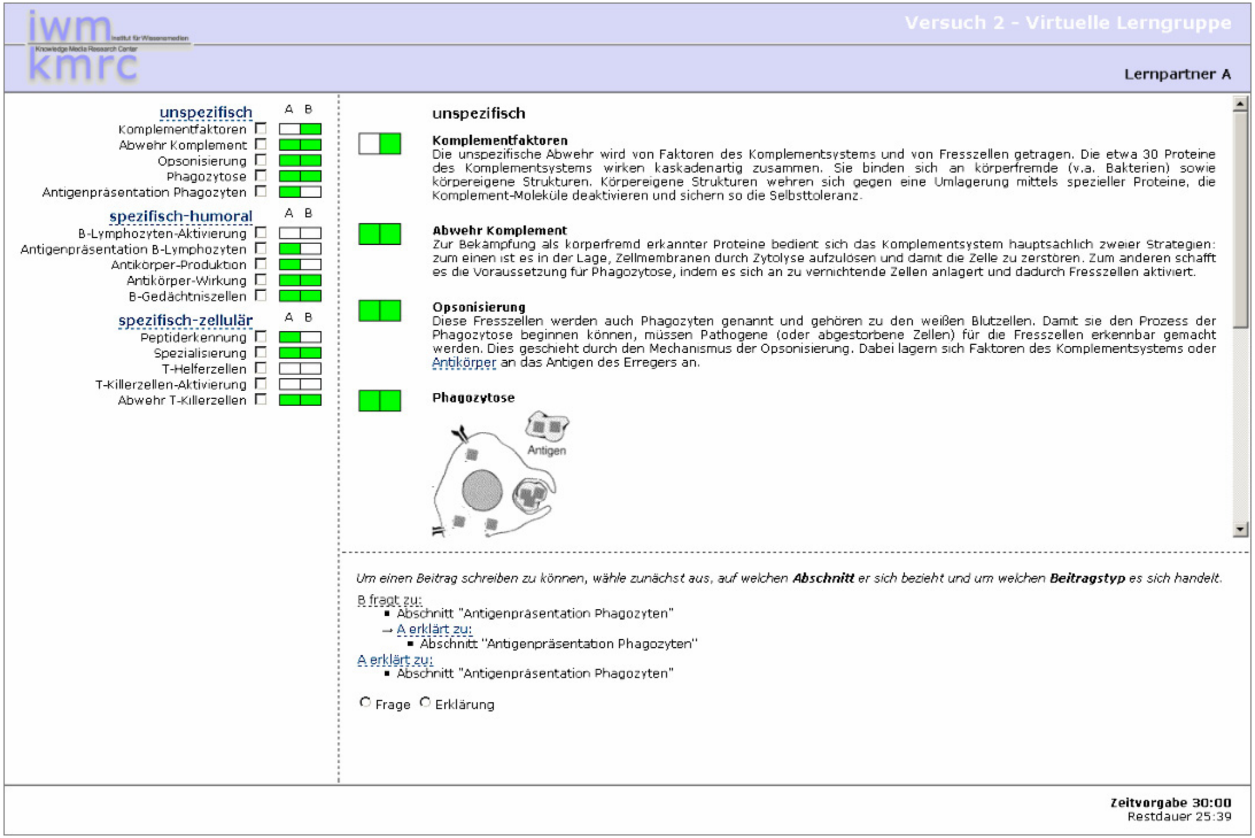

Figure 1. Learning environment in the collaboration task of the GKA condition with learning material on the upper right side, collaboration area on the lower right side, and knowledge awareness visualization on the left side.

understanding of the content would be sufficient to give an explanation to the partner. Green-colored boxes indicated positive evaluations, while white-colored boxes indicated negative evaluations. During self-assessment, no information about the state of the partner's knowledge assessment was available. Knowledge assessment could not be changed during the collaboration phase.

2.3.2. *Knowledge awareness visualization*

The knowledge awareness visualization provided learners with self-assessed knowledge, which was displayed next to the topic list separately for each dyad member (A or B). Small boxes next to each paragraph revealed knowledge (green box) and deficits (white box). In the control condition, only the participant's own knowledge was displayed as a white or green box accompanying each paragraph (i.e. the right column of boxes was missing). In the GKA condition, visualizations contained both a participant's (left column of boxes) and the respective partner's knowledge (right column of boxes). Thus, each paragraph was accompanied by two boxes, with each being either white or green. The combination of these two boxes resulted in paragraphs of shared knowledge (two green boxes), shared deficit (two white boxes), complementary partner knowledge (participant box white and partner box green), and complementary participant knowledge (participant box green and partner box white). This type of visualization allowed learners to easily compare their own and their partner's knowledge.

2.3.3. *Collaboration area*

Participants were provided with two buttons in order to select the type of contribution (question or explanation). Upon selection, a text field was opened and participants had to indicate to which paragraph their contribution refers by selecting the respective small reference box in the topic list. Contributions were displayed as thread. For each contribution, three attributes were provided in the thread view: author, contribution type (question or explanation), and reference paragraph. The contribution text was available when participants opened the thread link. After reading, participants could either return to the thread view or write a responding contribution. If contributions were written as a direct response to another contribution, they were displayed as subordinates in the thread.

2.4. ***Measures and analysis***

2.4.1. *Prior knowledge*

In a pre-experimental questionnaire, participants rated their prior knowledge subjectively on a five-point Likert scale (ranging from very low (1) to very high (5)). Knowledge was rated on five topics related to the learning material: immune system, blood, physiology, medicine, biology.

2.4.2. *Learning outcome*

Knowledge was assessed by a 27-item multiple-choice test administered after the experiment. Different types of knowledge were assessed in separate subtests: 15 items on factual knowledge (one item per paragraph of learning material) and 12 items on inferential knowledge. Responding correctly to items of inferential knowledge required participants to draw inferences based on information in different paragraphs of the learning material. Information was distributed either within one hypertext page (local inferential knowledge; 6 items) or across two hypertext pages (distant inferential knowledge; 6 items).

2.4.3. *Learning process*

Contrasting cases analysis has been described as a promising method to shed light on the relation between processes and outcomes in CSCL (Fischer *et al.*, 2008). Following the contrasting cases approach as explained by Onwuegbuzie and Teddlie (2003), we will provide a descriptive analysis of learning outcome data, select cases of low and high learning outcome in both conditions, and compare learning activities and learning mechanisms on the basis of additional communication data. Comparison focuses on the level of elaboration, interactivity, and coordination of activities.

To this end, communication threads were divided into statements. One statement contained one single unit of meaning covering one piece of information. This was in most cases identical to units generated by participants' punctuation in their thread contributions. A statement type was assigned to each statement. For each statement type, an exhaustive list of criteria was defined, which is shown in Table 1.

2.4.3.1. *Elaboration*

In order to assess the extent to which contributions elaborated on the content and even transformed what was already provided by the learning material, we coded all content statements to indicate whether or not they contain integration and extension. *Integration* was introduced as a criterion for the complexity of each statement with regard to the learning material and was based on its number of reference paragraphs: integrative statements referred to two or more paragraphs. *Extension* indicates a statement's complexity beyond the material: extension statements asked for or provided information going beyond what was directly available in the learning material.

2.4.3.2 *Interactivity*

Interactivity was described as a central dimension of collaborative learning as it not only tells how much learners contribute (like typical participation scores), but also how interrelated the learners' communication is, that is, how collaborative their learning is (Schrire, 2006). We identified whether or not content statements were interactive or stand-alone statements on the basis of three sources: (a) thread pattern: a statement was signified as reaction when participants contributed at a

Table 1. Definitions of statement types.

Statement Type	Definition and Example
Content	— Statement asks for or provides content. "What is the exact effect of cytokine?"
Knowledge awareness explication	— Statement asks for or provides information about one's own knowledge or understanding or the partner's knowledge or understanding. — Statement specifies the extent and manner of prior knowledge related to the learning domain. — Statement indicates the certainty of contributed information. "What do you not know?"
Coordination	— Statement refers to past, present, or future activities (e.g. who or how activities should be accomplished). — Statement refers to role distribution. "Ok, I will summarize this shortly."
Unspecific on-task	Statement refers to — the task (e.g. comments on its complexity), — the learning environment (e.g. its structure), — characteristics of the learning material (e.g. its organization), or — the communication scenario (e.g. its asynchronous character) without providing any content information. "I hope your contribution will be forwarded to me now."
Off-task	Statement is not related to the task. "Computer science *haha* male or female?"

subordinate level in the thread (i.e. the contribution is written as a reaction to the higher-level partner contribution), (b) references: a statement with a direct reference to a previous partner statement shows that it is a reaction (e.g. when another statement is quoted), and (c) content: statements reacting to a previous partner statement as regards content (e.g. providing content information that the partner asked for). A non-interactive stand-alone statement was either a question without a reply from the partner or an explanation that did not act upon a previous question and that the partner did not react to. High numbers of interactive statements indicate a rather collaborative approach to writing contributions, while low numbers of interactive statements indicate a rather individualistic approach.

For content question statements, we additionally determined responsivity. To this end, we identified whether or not a question received a reply. For all questions that received a reply, we additionally coded whether they received a reply from the partner or from the person posing the question. This indicator shows to what extent questions are responded to and by whom. The amount of partner-replies indicates to what extent learners receive help from the partner and solve comprehension problems collaboratively, whereas the amount of self-replies indicates to what extent learners solve their comprehension problems individually.

2.4.3.3 *Coordination*

We analyzed how activities were distributed among the partners of one dyad. Distribution of activities was measured as the relation between questions from partner

A and B and the relation between explanations from partner A and B, respectively. If, for example, partner A contributed 80% of all questions and 10% of all explanations (and consequently, partner B contributed 20% of the questions and 90% of the explanations), this reflects an asymmetric distribution of both activities, with A assuming the questioner role and B that of the explainer. This kind of coordination is expected for dyads with large knowledge differences (e.g. partner B knows much more than partner A according to the knowledge self-assessment), since, by asking questions, the less knowledgeable partner can benefit from the explanations of the more knowledgeable partner. That is, partners with high knowledge differences are expected to distribute activities asymmetrically, while partners with similar knowledge are expected to take over activities symmetrically. Put differently, the degree of asymmetry of activity distribution is expected to correspond to the degree of asymmetry of knowledge.

2.5. *Procedure*

Participants were seated in separate laboratory rooms. The whole experiment was conducted computer-based. Upon completion of an online questionnaire on prior knowledge and demographic characteristics, participants were introduced to all tasks of the experiment in an introductory phase (about 15 minutes) before they entered the main experimental phase (about 60 minutes). In the course of the introduction, subjects learned individually for three minutes, with one text page providing basic information on the immune system, while they self-assessed their own knowledge at the same time. Afterwards, knowledge awareness visualizations (learner's own knowledge in the control condition and both learner's and partner's knowledge in the GKA condition) were presented solely for 30 seconds with the instruction to think aloud in order to stimulate the processing of information in the visualization. Visualizations continued to be available but were supplemented by elements of the collaboration area (see Sec. 2.3.3) in the subsequent introductory collaboration task (eight minutes). All tasks recurred in the main experimental phase with longer execution times. The learning hypertext was available for 15 minutes for individual learning and knowledge assessment. Then, knowledge awareness visualizations were displayed for one minute while thinking aloud. They were also available throughout the subsequent 30-minute collaboration phase. Finally, participants completed both a knowledge test and a questionnaire.

3. Results

3.1. *Learning outcome*

Percentage scores of correct responses for factual, local inferential, and distant inferential knowledge subtests were calculated for each participant. Each dyads' learning outcome was determined as the mean value of both learners. In the factual knowledge subtest, outcomes of both conditions were rather similar, as GKA condition dyads arrived at 65.0% ($SD = 5.8$) correct responses and control condition dyads at 64.3% ($SD = 6.6$). Likewise, performance in the local inferential knowledge subtest in the GKA condition ($M = 56.0\%$, $SD = 4.9$) was similar to the control condition ($M = 56.6\%$, $SD = 7.8$). Scores for distant inferential knowledge were slightly higher in the GKA condition ($M = 69.5\%$, $SD = 7.3$) than in the control condition ($M = 66.6\%$, $SD = 7.5$). A one-factorial ANOVA revealed no differences of learning outcomes between conditions. Conditions also did not differ in prior knowledge ratings.

3.2. *Learning activities and mechanisms*

Both conditions appeared rather similar on outcome measures. In this paper, we investigate how GKA influences *how* (and not *how much*) dyads learn. We carried out a contrasting cases analysis (Onwuegbuzie & Teddlie, 2003) to reveal differences between conditions regarding learning activities and learning mechanisms (i.e. the relation between activities and learning outcome).

To this end, we identified dyads with the highest and the lowest learning outcome scores in both conditions. All dyads with at least two out of three knowledge subtest scores outside of a range — between one standard deviation above and below the mean, respectively — were selected for analysis. This procedure identified eight dyads: two control condition low learning outcome dyads, two control condition high learning outcome dyads, two GKA condition low learning outcome dyads, and two GKA condition high learning outcome dyads. Information about the dyads' scores concerning the indicators used in the learning outcome analysis are provided in Table 2. It shows that prior knowledge ratings were rather similar in all groups.

The analysis distinguishes learning activities and mechanisms. In order to reveal differences in collaborative learning activities, mean values among all selected dyads from one condition regarding the collaboration indicators are compared between

Table 2. Pre-test prior knowledge ratings, knowledge test scores, and differences of self-assessed knowledge (as shown in the tool) for low and high learning outcome dyads in both conditions.

Measure	Control Condition		GKA Condition	
	Low	High	Low	High
Prior knowledge	2.1 (0.9)	2.2 (0.4)	2.5 (0.4)	2.3 (0.4)
Factual knowledge (in %)	59.2 (5.9)	73.3 (3.5)	57.9 (4.1)	69.6 (1.8)
Local inferential knowledge (in %)	46.9 (1.5)	63.6 (4.4)	53.1 (4.4)	63.5 (7.4)
Distant inferential knowledge (in %)	58.3 (0.0)	76.0 (1.5)	58.3 (0.0)	78.1 (1.5)
Knowledge difference	6.5 (3.5)	4.5 (2.1)	5.5 (3.5)	3.5 (2.1)

Table 3. Mean and standard deviation (in parentheses) of statement types for low and high outcome dyads of both conditions, as well as overall per condition and difference between high and low learning outcome dyads.

Statement Measure	Control Condition				GKA Condition			
	Low	High	Overall	Diff.	Low	High	Overall	Diff.
Number of statements	43.0 (21.2)	35.0 (12.7)	39.0	−8.0	39.5 (2.1)	47.5 (24.8)	43.5	+8.0
% content	65.4 (38.8)	72.3 (28.3)	68.8	+6.9	77.00 (8.4)	77.3 (18.0)	77.2	+0.3
% knowledge awareness explication	10.3 (14.6)	14.1 (9.0)	12.2	+3.7	17.9 (8.1)	6.4 (0.4)	12.2	−11.5
% coordination	5.2 (7.3)	4.6 (6.4)	4.9	−0.6	2.5 (0.1)	3.2 (0.2)	2.9	+0.7
% unspecific on-task	11.3 (5.9)	10.2 (14.5)	10.8	−1.1	2.5 (0.1)	14.0 (15.1)	8.3	+11.4
% off-task	7.8 (11.0)	0.0 (0.0)	3.9	−7.8	0.0 (0.0)	0.8 (1.1)	0.4	+0.8

Table 4. Mean and standard deviation (in parentheses) of percentages of elaboration indicators for low and high outcome dyads of both conditions, as well as overall per condition and difference between high and low outcome dyads.

Elaboration Measure	Control Condition				GKA Condition			
	Low	High	Overall	Diff.	Low	High	Overall	Diff.
Integration	7.7 (10.9)	49.3 (22.6)	28.5	+41.6	18.4 (15.6)	40.0 (4.1)	29.2	+21.5
Extension	22.0 (20.3)	40.9 (28.3)	31.4	+18.8	37.7 (20.0)	48.0 (10.7)	42.9	+10.3

conditions (i.e. see "overall" per condition in Tables 3–5 for RQ1). Learning mechanisms were disclosed by identifying differences between low and high learning outcome dyads, which were subsequently compared between conditions (i.e. see difference ("diff") between high and low learning outcome dyads in Tables 3–5 for RQ2). This analysis gives insights into whether dyads of both conditions arrived at their level of learning outcome by similar or dissimilar mechanisms. Difference scores were calculated as the difference between high and low outcome dyads. Thus, positive difference scores show a positive relation between a process indicator and learning outcome, that is, a learning mechanism. Process data were analyzed regarding elaboration, interactivity, and coordination — preceded by a basic analysis of communication statements.

3.2.1. *Statement types*

Table 3 presents results of the statement type analysis. Comparing learning activities between conditions as to RQ1, we found that dyads with GKA contributed on

Table 5. Mean and standard deviation (in parentheses) of percentage of interactive statements, questions with reply, and partner as well as self-replies out of all replied questions for low and high outcome dyads of both conditions, as well as overall per condition and difference between high and low outcome dyads.

Interactivity Measure	Control Condition				GKA Condition			
	Low	High	Overall	Diff.	Low	High	Overall	Diff.
Interactive statements	50.9 (50.2)	53.7 (34.7)	52.3	+2.8	77.6 (9.6)	88.4 (5.3)	83.0	+10.8
Questions with reply	47.6 (26.9)	58.1 (2.7)	52.9	+10.5	71.7 (2.4)	83.3 (23.6)	77.5	+11.7
Partner-reply	100.0 (0.0)	55.6 (15.7)	77.8	−44.4	86.4 (19.3)	100.0 (0.0)	93.2	+13.6
Self-reply	0.0 (0.0)	22.2 (15.7)	11.1	+22.2	0.0 (0.0)	0.0 (0.0)	0.0	+0.0

average 4.5 more statements to the communication than control condition dyads. GKA dyads focused slightly more on content (77.2% vs. 68.8% content statements). Knowledge awareness was explicated to the same extent in both conditions. Control condition dyads generated slightly more coordination statements (4.9% vs. 2.9%), unspecific on-task statements (10.8% vs. 8.3%) and off-task statements (3.9% vs. 0.4%) than GKA condition dyads. These and the following descriptions of results have to be interpreted cautiously due to large standard deviations.

Regarding learning mechanisms (RQ2), we considered differences between high and low learning outcome dyads in each condition. The amount of content statements was higher for high compared to low outcome dyads in the control (+6.9%), but not in the GKA condition (+0.3%). The amount of explications of knowledge awareness differed only slightly between high and low outcome dyads in the control condition (+3.7%), while in the GKA condition high compared to low outcome dyads generated less knowledge explications (−11.5%). The difference scores for coordination statements were similar in both conditions. In the GKA condition, unspecific on-task statements occurred more often in high compared to low outcome dyads (+11.4%). Off-task statements occurred almost exclusively in low outcome control condition dyads.

3.2.2. *Elaboration*

Elaboration of content statements indicates if learners do not just re-tell in their contributions, but rather transform and go beyond their knowledge and the information provided in the text. Data are presented in Table 4. While dyads integrated several paragraphs to a similar extent in both conditions, GKA condition dyads tended to include more extensions beyond the material than control condition dyads (42.9% vs. 31.4%).

In both conditions, more integrative statements were found in high compared to low outcome dyads. Similarly, in both conditions, high outcome dyads went beyond the material in their statements more often than low outcome dyads. Thus, integration and extension seemed to operate as learning mechanisms in both conditions.

The degree of elaboration was introduced as an indicator of the quality of cognitive processes, because the elaboration level of a statement is attributable to the reflection of the individual who wrote the statement. Nevertheless, content elaboration affects not only learning by the statement producer, but also learning by the recipient, as well as the collaborative interaction. The following analysis sheds light on the relation between elaboration and interaction.

3.2.3. *Interactivity*

Interactivity indicates to what extent learning was a collaborative activity. The comparison of overall per condition revealed that GKA condition dyads' collaboration was more interactive than that of the control dyads (83.0% vs. 52.3%, cf. Table 5). GKA condition dyads appear to follow a more collaborative approach and control condition dyads a more individualistic approach. Considering difference scores in both conditions, we found that interactivity of statements appeared as relevant for learning only in the GKA condition (+10.8%).

The responsivity indicator shows to what extent questions received a reply and by whom. The amount of partner-replies demonstrates to what extent learning was a collaborative activity, whereas the amount of self-replies reveals to what extent learning was a self-oriented individual activity. Responsivity was higher, that is, a higher percentage of questions received an answer, in the GKA than in the control condition (77.5% vs. 52.9%, cf. Table 5). Self-replies occurred in the control condition only.

Exploring the learning mechanisms, we found that, in both conditions, questions received a reply more often in high outcome dyads than in low outcome dyads. However, the learning mechanism took a different shape in the two conditions. In the GKA condition, the amount of partner-replies appeared as the learning mechanism (+13.6%). In the control condition, partner-replies occurred even less in high than low outcome dyads (−44.4%) and the amount of self-replied questions appeared as learning mechanisms (+22.2%).

The following excerpt from a control condition high performing dyad further illustrates the individualistic learning mechanism.

A: "If *t*-lymphocytes are produced during division of *b*-lymphocytes — then how is it possible that *b*-lymphocytes are fully activated by *t*-lymphocytes?"

A: "*B*-lymphocytes are cells that take, process, and store information about pathogens. *T*-lymphocytes are the acting cells which actually fight against pathogens. Something like commander and mercenary. Thus, the relation consists in division of labor."

A's question can be characterized as elaborated comprehension-seeking question. The content that could satisfy the question as response (see e.g. Pilkington, 2001 on this indicator of question type) would be an explanatory elaborated answer rather than mere information. Typically, comprehension-seeking questions include "why", "how" etc. as interrogative (Graesser, Baggett, & Williams, 1996). The response *A* formulated on her own question is elaborated as well (using e.g. Bloom's cognitive taxonomy; Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956): functions of *b*-lymphocytes are described, a metaphor of their role is provided, and their interrelation with other parts of the immune system is analyzed. Thus, *A*'s own question seems to have triggered *A*'s elaboration.

In order to shed light on how replies influenced learning in the GKA condition we consider a sequence of a question and a partner-reply from one low and one high performing dyads' communication thread.

Low performing GKA dyad:

A: "What is an antigen?"
B: "On the membrane of the phagocytes are parts of the antigen. That is noting else than specific proteins of a pathogen."

The preceding excerpt is an example of shallow interaction. The question asks for definitional information, which could equally be found in the learning material. *B* responded adequately, that is, on the (low) level of elaboration that the question triggered, by providing factual information on antigens. Hence, collaboration was merely used for information exchange. Learning partners engaged in activities like information recall, reproduction, and reception.

High performing GKA dyad:

B: "Is the detection of peptides just a variant of opsonisation? In both cases the pathogen has to be marked somehow for one form of defence?"
A: "Opsonisation means that antibodies or complement proteins are chained on antigens of pathogens. As a consequence, antigens are detected as foreign particle by phagocytes and destroyed, that is innate immunity. The detection of peptides however, plays a role within adaptive immunity: there, *t*-lymphocytes detect peptides which are parts of antigens and begin with cell division for immune defence."

The preceding excerpt is an example of elaborated interaction. *B*'s comprehension-seeking question links two processes in a relation of similarity. *A*'s response includes descriptions of the processes in question and contrasts them by analyzing their respective functions within the immune system. Thus, *B*'s question seems to have triggered *A* to elaborate and extend the level of comprehension.

In sum, the differences in learning activities between high and low outcome dyads seem to be rather different in both conditions. Interactivity and interactive responsivity appeared to be more important for the GKA than the control condition dyads. In contrast, control condition learning outcomes corresponded to self-generated responsivity. Taken together with results from elaboration analysis, it seems that high elaboration, which is advantageous for learning in both conditions, is achieved differently: by individual elaboration in the control condition and by collaborative elaboration in the GKA condition.

3.2.4. *Coordination*

Following the analysis of elaboration and interactivity, learning outcome seems to be related to the amount and quality of interaction for the GKA, but not the control condition dyads. Thus, a deeper analysis of collaboration practices is most insightful for the GKA condition. For the control condition, however, further analysis of the practices and quality of collaboration is not expected to provide relevant findings due to rather individualistic learning mechanism. Hence, coordination analysis focused on GKA condition dyads. We investigated how questions and explanations were distributed among partners of a dyad, thereby assessing the *empirical* distribution of activities. Based on the knowledge difference between partners of a dyad (as displayed in the knowledge awareness visualization), we determined an *expected* distribution of activities: the higher the knowledge difference in a dyad the more asymmetrical their activities are expected to be coordinated. By comparing empirical and expected distributions of activities, we inferred if dyads coordinated their interaction as to their knowledge differences.

Table 6 informs about empirical and expected distribution of activities in GKA condition dyads. Numbers in Table 6 indicate the percentage of questions and explanations contributed by one partner. Maximal symmetrical activity distribution would be found if both learning partners contributed each 50% of questions and 50% of explanations. Maximal asymmetry of one or both contribution types would be represented by 100% of questions or/and 100% of explanations.

Knowledge difference was small (number of green-coloured boxes per person: *A*: 8, *B*: 11; i.e. difference 3) in one of the low outcome dyads and large (*A*: 6, *B*: 14) in the other; similarly, knowledge difference was small (*A*: 7, *B*: 9) in one of the high outcome dyads and large (*A*: 10, *B*: 15) in the other. The empirical activity distributions revealed that the low learning outcome/small knowledge difference

Table 6. Empirical and expected distribution of activities in GKA dyads with low/high learning outcome and small/large knowledge difference.

Distribution of Activities	Learner	Low Learning Outcome				High Learning Outcome			
		Small Knowledge Difference		Large Knowledge Difference		Small Knowledge Difference		Large Knowledge Difference	
		Empiric	Expected	Empiric	Expected	Empiric	Expected	Empiric	Expected
% of questions	*A*	60.0	71.4	73.3	94.5	33.3	62.5	100	100
	B	40.0	28.6	26.7	5.5	66.7	37.5	0	0
% of explanations	*A*	50.0	28.6	55.6	5.5	70.6	37.5	0	0
	B	50.0	71.4	44.4	94.5	29.4	62.5	100	100

dyad did not distribute activities to a large extent. Partners in the low outcome/large knowledge difference dyad distributed questions but not explanations and participated to an unequal extent. For high learning outcome dyads, asymmetry was medium in the small knowledge difference dyad and strong in the large knowledge difference dyad.

We analysed if activities were distributed according to knowledge differences. Generally speaking, for dyads with large knowledge differences, a highly asymmetrical distribution of activities is expected (i.e. the more knowledgeable partner explains to the less knowledgeable partner who asks questions). For dyads with small knowledge differences, a rather symmetrical distribution of activities is expected (i.e. both partners contribute explanations as well as questions). The expected activity distribution takes into account the knowledge difference and how helpful the more knowledgeable partner could be for the less knowledgeable partner. The expected distribution indicates how asymmetric the dyads are expected to coordinate given their knowledge differences (i.e. how far from 50% of questions and explanations for each partner). For example, the low outcome/large knowledge difference dyad had a knowledge difference of 8 (partner values: A: 6, B: 14). The less knowledgeable partner self-assessed 6 out of 15 paragraphs as knowledge, thereby leaving 9 paragraphs as deficit. The more knowledgeable partner could provide help for 8 out of these 9 paragraphs (89%). Therefore, the dyad is expected to diverge to 89% from a symmetrical (50/50) distribution (i.e. the more knowledgeable partner is assumed to contribute 94.5% $(= 50\% + (50\% * 89\%))$ of all explanations, see Fig. 2). (Various measures for the expected distribution are conceivable. We consider the one chosen here to be most appropriate and rather conservative.)

Low outcome dyads' coordination of activities differed from expected distributions, as the more knowledgeable partners provided fewer explanations in comparison to their less knowledgeable partners than expected. In contrast, the high outcome dyad with a large knowledge difference coordinated the interaction as expected with the more knowledgeable partner having fully taken the explainer role and the less knowledgeable partner having fully taken the questioner role. Thus, coordinating in line with knowledge differences appeared as a learning mechanism when knowledge differences are large: the respective high outcome dyad was closer to the expected activity distribution than the low outcome dyad. Future studies and more data are needed to substantiate the observation that coordination which corresponds to knowledge differences can be related to better learning.

A closer look at the communication threads is taken in order to understand how the GKA condition dyads coordinated their interaction. In high outcome dyads, one statement related to the coordination of activities was found at the beginning of communication. This statement triggered a rather symmetrical activity distribution in the small knowledge difference dyad ("So, obviously we have both understood about the same."), but an asymmetrical distribution in the large knowledge difference dyad ("Well then, pose your questions on the topics you did not understand."). In contrast, low outcome dyads directly entered the communication with content statements and the coordination of activities was instead established by activities. For example, the more knowledgeable partner B in the low outcome/large knowledge difference dyad started the communication by posing questions, thereby not taking the explainer role. It seems that a coordination statement both explicitly and early in the collaboration supports coordination and thereby learning outcome.

4. Discussion and Conclusions

In this study, we provided collaborative learners with a tool that visualized information about a partner's as well as the learner's own knowledge: a group knowledge awareness tool. Dyads with and without the GKA tool performed similarly in learning outcome measures. Contrasting cases analysis for eight dyads (the two best and two worst from each condition) was dedicated not only to finding out more about the influence of the GKA tool on the collaborative activities, but also to shedding light on learning mechanisms with and without the tool. With the GKA tool, communication statements concentrated more on content, and collaboration was more interactive. We found some indication that the level of elaboration was positively associated with outcome, independent of the tool. However, high performing dyads with versus without the GKA tool differed in terms of how they arrived at high levels of elaboration. Elaboration without the GKA tool appeared to depend on the quality of individual activities thereby indicating an individualistic learning mechanism. With the GKA tool, elaboration appeared to depend on the quality of collaborative interaction thereby indicating a collaborative learning mechanism. The analysis of coordination indicated that learning outcome seemed to be influenced by whether or not collaborators coordinated their activities according to their knowledge distribution when knowledge differences were large.

One main conclusion of the present paper is that GKA tools affect the focus (individual vs. collaborative) of learning activities. Outcome of control condition dyads (i.e. provided with visualizations of the learner's own, but not the partner's knowledge) was associated with whether they effectively engaged in self-generated elaboration. The representation of their own knowledge might have triggered self-regulation processes (which might account for the lack of differences in learning outcomes, as it might have fostered learning in the control condition). This provides evidence for the argument that collaboration does not necessarily occur just because a collaborative learning environment is available (Brown & Palincsar, 1989; Kreijns, Kirschner, & Jochems, 2003). Being additionally provided with information on the partner's knowledge seems to shift learner attention from their own to their partner's knowledge and to their collective knowledge distribution. In that sense, GKA did not just provide more information to learners, it also changed how they processed and reacted to tool information. Hence, learning activities can be influenced by GKA visualizations in a similar way as they are influenced by representational notifications of learning tasks (i.e. a representational guidance effect as described by Suthers and Hundhausen, 2003).

A second main conclusion is that GKA was not consistently used for coordination of activities according to the knowledge distribution. One reason for this might be that some collaborators did not consider the GKA tool to be exclusively useful for coordination of activities. This is supported by the observation that higher amounts of knowledge awareness explication was found in low compared to high outcome GKA condition dyads. Low outcome dyads mainly used knowledge awareness explication to supplement information presented in the GKA tool. The conversational effort of providing additional information could be reduced by implementing a dynamic GKA tool that allows learners to modify their own knowledge representations during the collaboration. Recent research revealed that dynamic GKA tools can support collaborative learning (Bodemer, 2007).

Another reason for inefficient use might be that collaborators did not know how to translate the knowledge distribution presented in the tool into coordinated activities. This suggests that the functionality of GKA tools should be augmented to support this translation. For example, GKA tools could provide learners with instructional advice on how to use its information (cf. guiding tools according to Soller, Martinez, Jermann, & Muehlenbrock, 2005). The instructional support could take two forms. First, general instructions could be given prior to collaboration (e.g. recommending a symmetrical distribution of activities for joint co-construction of knowledge in the case of equal knowledge between partners). Second, specific instructions on adequate next activities could be embedded in the tool (e.g. proposing to give an explanation to the partner who indicated a lack of understanding on that topic). Instructions that guide collaborative learners in building common ground, for example, by advising them to externalize unshared knowledge, have been shown to facilitate the establishment of shared understanding (Kirschner, Beers, Boshuizen, & Gijselaers, 2008). Thus, the combination of such instructions and a GKA tool seems promising. Implementing this functionality as an option and not as forced "advice" preserves learners' self-regulation possibilities and the groups' freedom to manage collaboration themselves (Dillenbourg, 2002). Providing instructions early on in the collaboration is suggested by our observation that early and explicit coordination statements were beneficial, as well as recent research showing that early phases of collaboration are crucial for group performance (Kapur, Voiklis, & Kinzer, 2008).

Having discussed possible future extensions of GKA tools, the question remains if such augmented tools can be assumed as helpful irrespective of the knowledge difference within a dyad. Sangin *et al.* (2008) report a higher benefit from their GKA tool (which did not feature comparability) for groups with asymmetric knowledge versus symmetric knowledge. The study reported in this paper, however, indicated that dyads with both large and small knowledge differences could benefit from the GKA tool and achieve high learning outcomes. The mechanisms, however, can differ. For example, using the information about the knowledge distribution to coordinate collaboration seemed to be important for learning in dyads with large knowledge differences. For the application of GKA tools in educational practice, we, therefore, cautiously conclude that tools providing comparable knowledge information can be helpful for tutor-tutee-like scaffolded learning scenarios, as well as peer co-construction of knowledge.

We presented a GKA tool with features that allow an easy application of the tool in technology-enhanced collaboration environments. As the GKA tool relies on self-assessment, content is generated without high external effort (as compared, for example, to knowledge assessed by objective test measures). Learners might even benefit from self-assessment, as it can trigger meta-cognitive reflection about their knowledge and their knowledge gaps. The use of self-assessment allows the flexible adaptation of this tool, not only to different learning issues and domains, but also to different learning settings, from peer learning to tutoring and teaching. In the latter cases, self-assessment could also be supplemented by teacher knowledge assessment with the positive side effect of diagnosing potential discrepancies between students' self-assessment and teacher assessment. Teacher assessment could even be the only source of information to be used in the GKA tool. Thereby, possible inter-individual differences between students in self-assessment behavior could be eliminated and more comparable knowledge information could be offered to students. Irrespective of the source of knowledge assessment, supplementary support for using GKA tools for collaboration, such as the above discussed general and specific instructions on using GKA information, could be complemented or covered entirely by the teacher. We observed that the GKA tool directed learners towards a collaborative (as opposed to an individualistic) learning approach. Hence, using GKA tools in educational practice seems most useful when such a collaborative focus is intended in the particular teaching/learning situation or when collaboration competence itself is the learning objective. But, of course, empirical research on the use of GKA tools in educational practice is needed to substantiate the considerations made in this paper. For the time being, we consider GKA tools to be an easy-to-adopt support for GKA that can foster collaborative learning.

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