Providing Knowledge-Related Partner Information in Collaborative Multimedia Learning: Isolating the Core of Cognitive Group Awareness Tools

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Abstract: Cognitive group awareness tools support learners in dealing with specific challenges of computer-supported collaborative learning scenarios. This paper suggests three supporting functions underlying cognitive group awareness tools and proposes to disentangle them in three consecutive experimental studies with regard to multimedia learning. It focuses on one of those studies that systematically investigates whether providing knowledge-related partner information can improve collaborative learning with multiple external representations and with dynamic and interactive visualizations. Learning dyads (N = 120) were compared in four groups that differed with regard to the presentation of knowledge-related partner information during two subsequent collaboration phases: (1) learning with multiple static representations and (2) learning with dynamic and interactive visualizations. Results indicate that providing partner information during collaboration can facilitate meaningful learning discourses and improve learning outcomes.

Keywords: computer-supported collaborative learning, cognitive group awareness, multiple external representations, interactive visualizations

1. Introduction

Collaborative multimedia learning is a promising but challenging scenario. Learning partners have to overcome individual as well as specific collaborative barriers simultaneously (Bodemer, Kapur, Molinari, Rummel, & Weinberger, 2011; Bromme, Hesse, & Spada, 2005; Dillenbourg & Bétrancourt, 2006). With regard to individual multimedia learning, research addressed various difficulties of learning with multiple external representations (MER; e.g., Ainsworth, 2006) or dynamic and interactive visualizations (DIV; e.g., de Jong & van Joolingen, 1998). Moreover, when learning collaboratively, learners have to additionally (1) establish references between external content and communication, (2) construct a common ground based on mental representations of their learning partners' knowledge, and (3) coordinate communication and interaction processes in a goal-oriented way (cf. Bodemer, 2011; Clark & Brennan, 1991).

This paper focuses on cognitive group awareness (CGA) tools that support learners in dealing with the specific challenges of computer-supported collaborative learning (CSCL). It has been shown that they can improve collaboration processes and learning outcomes while enabling self-regulated learning processes (cf. Bodemer & Dehler, 2011; Janssen & Bodemer, 2013; Ogata & Yano, 1998). Moreover, CGA tools are suited to be combined with instructional tasks well-proven in multimedia learning research. It was already shown that they can significantly support collaborative learning with both MER (e.g., Bodemer, 2011) and DIV (Scholvien & Bodemer, 2013).

As a core feature, cognitive group awareness tools provide knowledge-related information on learning partners (e.g., a learning partner's hypotheses, test scores, interests or opinions), which can facilitate grounding and partner modeling processes during collaborative learning. Group awareness tools usually provide further support in two ways. On the one hand, knowledge-related information on learning partners do not only comprise information on a person but also refer to specific and often preselected content (e.g. a learning partner's hypothesis regarding a single element of the learning material), thereby cueing essential information of the learning material and constraining content-related communication. On the other hand, group awareness tools frequently provide information in a way that allows for comparing learning partners (e.g. adjacently presenting hypotheses of two learning partners), thereby guiding learners to discuss particularly beneficial issues (e.g. conflicting hypotheses as nudges for collaboratively elaborating divergent perspectives).

While all three tool features can potentially support learners in overcoming CSCL challenges, they are usually applied and investigated in combination. Thus, it is an open research question if the positive learning effects of providing group awareness information are based on only one, on two, or on all three features. In order to disentangle the effects of the underlying supporting functions in CGA tools, we propose three consecutive experimental studies that systematically vary only one of the tool features in each study (see Table 1).

Table 1: CSCL challenges and CGA tool support in collaborative multimedia learning.

CSCL Challenge	Tool Feature	Support/Function	Study
connecting communication and learning material	information cueing	constraining content-related communication	1
establishing a common ground	providing partner information	partner modeling	2
structuring the learning discourse	visualizing knowledge constellations	socio-cognitive guidance	3

Study 1 already showed that cueing relevant information in MER- and DIV-based learning material focuses learners' attention and communication to essential aspects and improves learning outcomes (Scholvien & Bodemer, 2013). This paper reports results of the second study that investigates the core feature of CGA tools (i.e., providing knowledge-related partner information). It is investigated if this feature is effective in addition to the beneficial effect of information cueing. It is hypothesized that providing partner information facilitates partner modeling, guides learning processes, and enhances learning outcomes during MER-based and DIV-based collaboration.

2. Method

2.1 Design and Procedure

In this experimental study, learning dyads were individually provided with interdependent learning material comprising either visual or algebraic information about the analysis of variance (ANOVA). Afterwards, learning partners collaborated in two subsequent phases in which they were instructed to collaboratively elaborate on statistics concepts and interrelations by means of different multimedia learning material:

During the first collaboration phase, learners are provided with static multiple external representations (MER), i.e. visualization (VANOVA; Oestermeier & Barquero, 2001) and formula components regarding the one-way analysis of variance such as observed values, experimental groups, means, sums of squares, mean squares, and F ratio.

During the second collaboration phase, this visualization was augmented by several dynamic and interactive components (DIV) that enabled participants to modify visual components (e.g., number of observed values and of experimental groups; size of observed values and group means) and to monitor the resulting effects on other components (e.g., sums of squares, mean squares, and F ratio).

Additionally, in each collaboration phase, partner information was provided in two of the four experimental groups, thus leading to four different experimental groups (MER0_DIV0 vs. MER1_DIV0 vs. MER0_DIV1 vs. MER1_DIV1; cf. Figure 1). Both collaboration phases were operated using a Samsung SUR40 multi-touch tabletop with Microsoft PixelSense that enabled face-to-face communication between learning partners as well as the synchronous manipulation of the ANOVA animation.

Prior to each collaboration phase, learners indicated their individual knowledge, i.e. assumptions on different elements and relationships within the ANOVA. Individual knowledge tests were conducted before (KT 1) and after each collaboration phase (KT 2 and 3; see Figure 1). Each knowledge test comprised three different subtests to measure conceptual knowledge, representational transfer (Bodemer, 2011) and intuitive knowledge (Swaak, de Jong, & van Joolingen, 2004). All test items were designed as multiple choice questions, including one correct answer and three distractors.

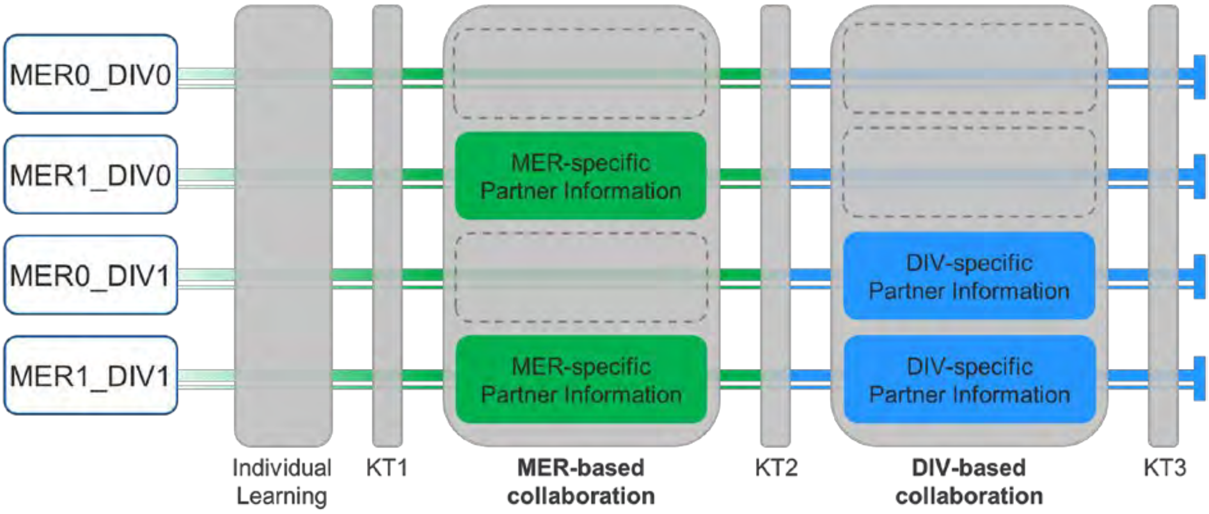

Figure 1. Experimental procedure differing with regard to four experimental groups.

2.2 MER-based Collaboration

Prior to the actual collaboration, each learner was requested to externalize her/his assumptions on MERs by individually integrating 13 formula-based elements into according parts of a static visualization via drag and drop. This integration task repeatedly proved to effectively support representational transfer and deep learning in individual MER-based learning scenarios (e.g., Bodemer, Ploetzner, Feuerlein, & Spada, 2004).

During the following first collaboration phase (15 minutes), learners were provided with differently coded learning material. The essential algebraic and visual elements were color-highlighted in all groups in order to keep the first CGA design feature invariant (see Figure 2a). To support partner modeling processes in two of the four experimental groups, each learner's prior assignments were presented to the respective learning partner (MER1_DIV1 and MER1_DIV0; see Figure 2b).

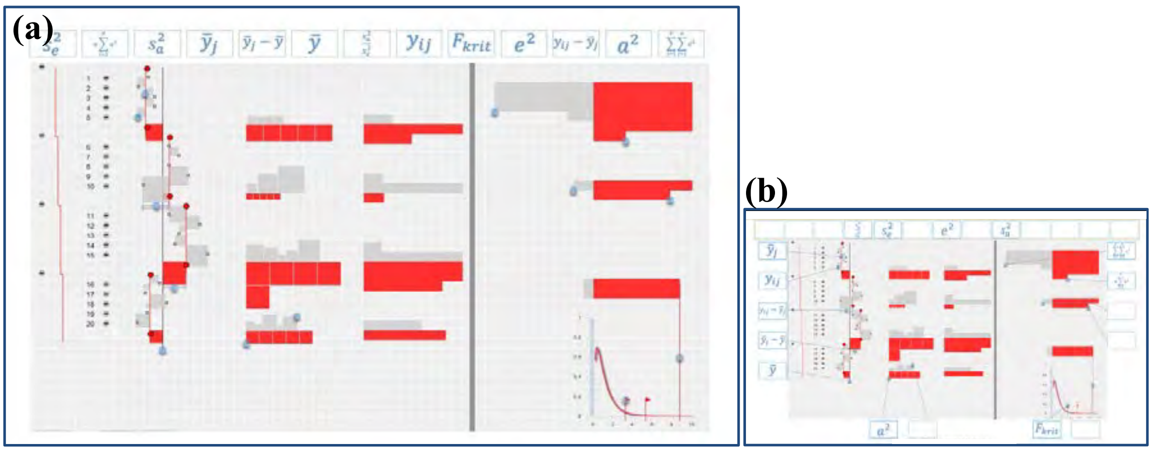

Figure 2. Screen captures of collaboration phase 1: (a) static multiple external representations (all experimental groups), (b) partner assignments (supported groups only).

As learners should not see their own assignments (enabling a comparison between own and partner information will be investigated in study 3), partner information was provided on additional laptops, which were arranged adjacently to the multi-touch tabletop.

2.3 DIV-based Collaboration

Analogous to the MER-based phase, learners externalized assumptions on the learning material in advance to the DIV-based collaboration phase. Each learner constructed eight hypotheses regarding interrelations of ANOVA elements using a set of predefined phrases (see Figure 3b). With respect to simulation-based discovery learning, a number of studies verified positive effects of supporting learners in generating hypotheses on collaborative processes as well as individual learning (e.g. Gijlers & de Jong, 2009; Scholvien & Bodemer, 2012; van Joolingen & de Jong, 1991).

In the following second collaboration phase (20 minutes), the visualization was enriched by several dynamic and interactive components, e.g. dragging a group mean to increase or decrease it. Essential causal relations between key elements of the ANOVA were provided beneath the animation (see Figure 3a), which, in a previous study, showed to beneficially affect learning partners' discourse as well as their individual learning outcomes (Scholvien & Bodemer, 2013). In addition, learners were provided with cognitive partner information in two of the four experimental groups. Each learner's prior hypotheses were presented to her/his respective learning partner (MER1_DIV1 and MER0_DIV1; see Figure 3b). Again, partner information was provided on additional laptops that were arranged adjacently to the multi-touch tabletop.

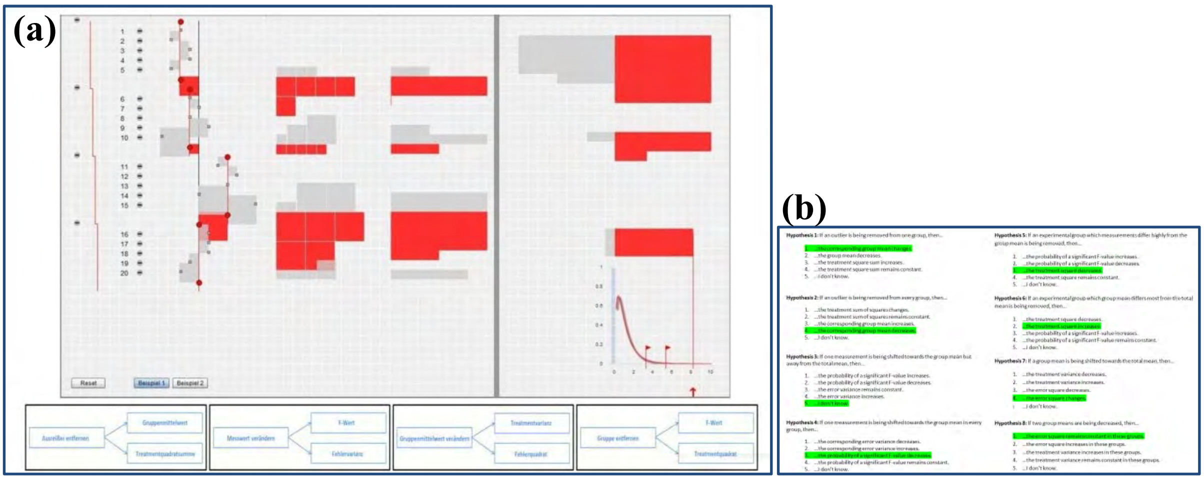

Figure 3. Screen captures of collaboration phase 2: (a) dynamic and interactive visualization (all experimental groups), (b) partner hypotheses (supported groups only).

2.4 Participants

In total, 120 university students (80 females and 40 males), aged 18-36 years (M = 22.38, SD = 2.93), were randomly paired into 60 dyads and subsequently randomly assigned to the four experimental groups. Participants were either paid or given a certificate needed for credits. All participants were recruited among students of a psychology-oriented degree program at the University of Duisburg-Essen, Germany, and had a basic knowledge of statistics concepts underlying the one-way analysis of variance.

3. Results

Due to the complex nature of the learning scenario, and to better comprehend the underlying individual and collaborative learning processes, a combination of qualitative and quantitative analyses has been applied to the data. Some analyses are still to be processed. However, essential results can be presented in the following.

3.1 Learning Outcomes

To investigate the effect of providing partner information on learning outcomes, individual learning was measured by three knowledge tests, which had to be performed prior (knowledge test 1) and subsequent (knowledge tests 2 and 3) to the collaboration phases. Each knowledge test was designed to measure conceptual knowledge, representational transfer, and intuitive knowledge. As intra-class correlations (Kenny, Kashy & Cook, 2006) regarding both post-knowledge tests revealed no interdependence within learning dyads, knowledge test scores were analyzed on an individual level.

With regard to prior knowledge (knowledge test 1), a two-way ANOVA with the factors *MER-specific partner information* (with vs. without) and *DIV-specific partner information* (with vs. without) showed no significant differences between the experimental groups (MER: $F(1, 116) = 0.58$, $p = .450$, $\eta^2 = .005$; DIV: $F(1, 116) = 0.02$, $p = .900$, $\eta^2 = .000$; MER x DIV: $F(1, 116) = 0.06$, $p = .801$, $\eta^2 = .001$). Equivalent ANOVAs were performed on knowledge tests 2 and 3 (for means and standard deviations see Tables 2 and 3).

After MER-based collaboration, particularly the main effect for providing MER-specific partner information is informative. As hypothesized, learners scored higher in knowledge test 2 (see Table 2) if they were provided with their learning partner's MER-assignments during the first collaboration phase ($F(1, 116) = 4.55$, $p = .035$, $\eta^2 = .038$). According to expectations, means did not differ significantly with regard to the presentation of *DIV-specific partner information* ($F(1, 116) = 0.02$, $p = .961$, $\eta^2 = .000$) and the interaction of both factors ($F(1, 116) = 0.12$, $p = .729$, $\eta^2 = .001$).

Table 2: Means and standard deviations for scores (%) in knowledge test 2 (after MER-based collaboration).

		MER-specific partner information					
		yes		no		overall	
		M	*(SD)*	*M*	*(SD)*	*M*	*(SD)*
DIV-specific partner information	yes	44.81	(19.24)	38.15	(20.15)	41.48	(19.82)
	no	46.30	(20.86)	37.04	(21.51)	41.67	(21.52)
	overall	45.56	(19.91)	37.59	(20.67)	41.57	(20.60)

Complementary to MER-based collaboration and knowledge test 2, after DIV-based collaboration (knowledge test 3; see Table 3) particularly the main effect for providing DIV-specific partner information is informative. As expected, learners provided with their learning partner's hypotheses outperformed those learners without CGA support in this learning phase ($F(1, 116) = 29.84$, $p < .001$, $\eta^2 = .205$). No significant differences occurred in this test regarding the factor *MER-specific partner information* (MER: $F(1, 116) = 0.33$, $p = .565$, $\eta^2 = .003$) and regarding the interaction of both factors (MER x DIV: $F(1, 116) = 0.03$, $p = .866$, $\eta^2 = .000$).

Table 3: Means and standard deviations for scores (%) in knowledge test 3 (after DIV-based collaboration).

		MER-specific partner information					
		yes		no		overall	
		M	*(SD)*	*M*	*(SD)*	*M*	*(SD)*
DIV-specific partner information	yes	57.59	(12.07)	56.48	(16.32)	57.04	(14.24)
	no	43.15	(18.78)	41.11	(11.36)	42.13	(15.42)
	overall	50.37	(17.26)	48.80	(15.95)	49.58	(16.57)

3.2 Partner Modeling

Providing partner information is expected to facilitate partner modeling, that is constructing a mental representation of the learning partner's assumptions. In order to estimate the modeling success, participants were asked to recall their learning partner's assumptions after each collaboration phase (MER-assignments after phase 1 and DIV-related hypotheses after phase 2). On this basis, the percentage of correctly memorized partner assignments could be determined. For means and standard deviations see Table 4 (assignments after MER-based collaboration) and Table 5 (hypotheses after DIV-based collaboration).

Analogous to the learning outcomes, learners performed better when they were provided with partner information in the respective collaboration phase (significant main effect for MER-specific partner information after MER-based collaboration: $F(1, 116) = 14.17$, $p < .001$, $\eta^2 = .109$; significant main effect for DIV-specific partner information after DIV-based collaboration: $F(1, 116) = 7.14$, $p = .009$, $\eta^2 = .058$).

Table 4: Means and standard deviations for correctly memorized partner assignments (%) after MER-based collaboration.

		MER-specific partner information					
		yes		no		overall	
		M	*(SD)*	*M*	*(SD)*	*M*	*(SD)*
DIV-specific partner information	yes	52.67	(25.45)	34.00	(21.11)	43.73	(25.04)
	no	49.33	(30.51)	32.67	(24.90)	41.00	(28.86)
	overall	51.00	(27.90)	33.33	(22.90)	42.17	(26.92)

Table 5: Means and standard deviations for correctly memorized partner hypotheses (%) after DIV-based collaboration.

		MER-specific partner information					
		yes		no		overall	
		M	*(SD)*	*M*	*(SD)*	*M*	*(SD)*
DIV-specific partner information	yes	43.33	(31.74)	38.89	(31.66)	41.11	(31.51)
	no	31.11	(23.05)	23.33	(26.48)	27.22	(24.92)
	overall	37.22	(28.19)	31.11	(29.98)	34.17	(29.14)

3.3 Interaction and communication behavior

To enrich the quantitative data on a deeper, more qualitative level, an insight into typical collaboration processes will be given. Therefore, the collaborative discourse of two learning dyads is illustrated and compared regarding prototypical interaction and communication patterns during their MER-based collaboration (with CGA support: Figure 4; without CGA support: Figure 5).
Figures show the communication and interaction sequence with regard to highlighted elements of the learning material (numbers in green circles) and the duration of each step of this sequence (circle size). For means of illustrating the collaborative discourse related to the learners' knowledge, all MER-assignments were added to the illustration even if they were not provided to the learners during collaboration. Assignments that were not visible to the learners are greyed out. Moreover, unequal MER-assignments (only one of the learners assigned a formula element to a particular visual element or both learners assigned different elements) are indicated by red dashed boxes.

The dyad provided with cognitive partner information (cf. Figure 4) interacted in a very structured way. First, the learning partners mainly searched for and addressed unequal assignments in the left part of the visualization (1-5), trying to clarify and solve knowledge-related conflicts. Then they continued with this systematic approach on the right and the lower right side of the visualization (6, 9-11) and thus managed to identify and discuss all unequal assignments during the first half of the collaboration phase. After this initial work on unequal assignments, the two learners very briefly affirmed assignments they already agreed with each other. Finally, this learning dyad used the remaining collaboration time to revise the solutions regarding their initial unequal assignments (14-16), which led to a deep collaborative elaboration of involved concepts and high learning outcome.

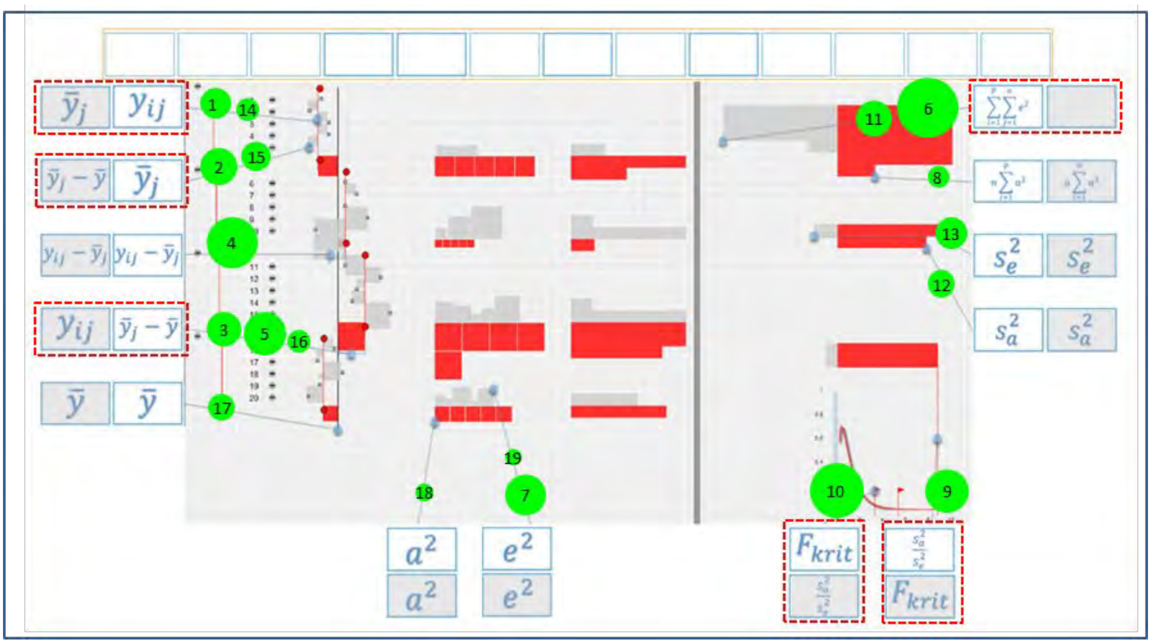

Figure 4. Prototypic MER-collaboration sequence *with partner assignments* (numbers indicate sequence of discussion, circle size indicates duration of collaboration, assignments not visible to the learners are greyed out, unequal assignments are indicated by dashed boxes).

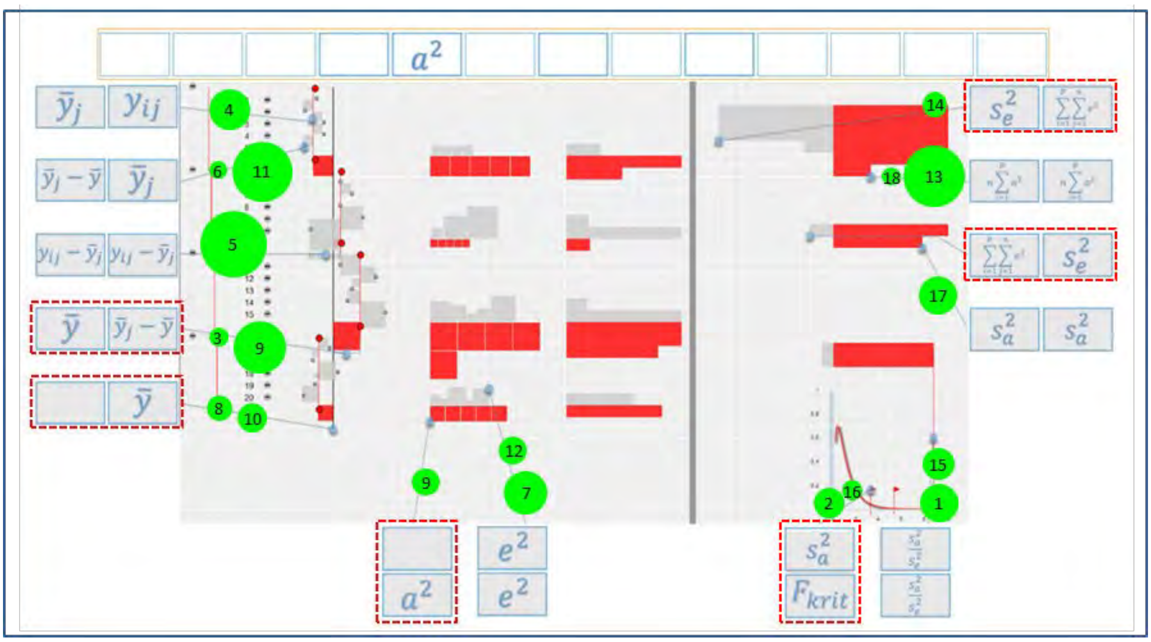

Figure 5. Prototypic MER-collaboration sequence *without partner assignments* (numbers indicate sequence of discussion, circle size indicates duration of collaboration, assignments not visible to the learners are greyed out, unequal assignments are indicated by dashed boxes).

Learners in the unsupported dyad (cf. Figure 5) did not use the given time just as effectively. Their learning discourse was not structured in terms of knowledge constellations, that is they did not focus on searching for and discussing divergent knowledge. Rather, learning partners clarified higher-level concepts (1-2) before systematically discussing the visualization from its left part (3-6, 9-11) via its bottom part (7, 9, 12) to its right part (13, 14, 17, 18). Thereby, this learning dyad spent more time and effort on talking about assumptions they already agreed on. Consequently, they failed to identify and discuss all unequal assignments and were not able to use the learning potential of discussing controversial positions thoroughly.

4. Discussion

The presented study was the second in a series of three experimental studies that investigate functions of cognitive group awareness tools in a complex collaborative multimedia learning scenario. Overall, it confirms the expected beneficial effects of providing knowledge related partner information on learning.

Regarding learning outcomes, in both collaboration phases learners provided with learning partner assignments performed significantly better than learners without additional collaboration support. However, this benefit was found for the respective collaboration phases only, indicating that there is no transfer effect for group awareness support from one collaboration phase with CGA support to a subsequent unsupported phase. Thus, providing cognitive information on the learning partner can support conceptual learning but does not seem to instruct useful metacognitive knowledge about grounding processes. Moreover, in contrasts to findings regarding individual multimedia learning scenarios (e.g., Bodemer, Ploetzner, Bruchmüller & Häcker, 2005; Swaak, van Joolingen, & de Jong, 1998), higher representational and conceptual knowledge of supported learners after MER-based learning did not lead to better learning during subsequent collaboration with dynamic and interactive material.

Furthermore, it was hypothesized that providing cognitive partner information directly facilitates modeling processes of constructing a mental representation of the learning partner's knowledge or assumptions. This hypothesis was supported by an increased ratio of correctly reminded assumptions of the learning partner when learners were provided with CGA support. Supported learners seem to have better detected partner information and to have used it for efficient grounding processes and better learning.

Finally, a first, qualitative analysis of typical learning dyads demonstrates how learners provided with knowledge-related partner information can collaborate in a very systematic and beneficial way. They can successfully and effectively identify knowledge-related conflicts and, on this basis, engage in deeper, more elaborated communication. Although these data need to be analyzed in a much more comprehensive way, these first indications are consistent with a number of studies which emphasize the importance of negotiating knowledge-related conflicts (e.g. Mugny & Doise, 1978; Webb, 1989; Weinberger, Marttunen, Laurinen & Stegmann, 2013).

Overall, the results indicate that providing cognitive partner information supports different types of collaborative multimedia learning in many aspects. In addition to overall effects of GA tools (cf. Janssen & Bodemer, 2013) and to the beneficial function of cueing relevant information (Scholvien & Bodemer, 2013), the core feature of CGA tools showed positive effects on essential learning processes and learning outcomes. The third experimental study in this series will reveal whether the third proposed design feature (visualizing knowledge constellations for comparing learning partners) is as effective for collaborative multimedia learning as the two already investigated have shown to be.

Acknowledgements

This research was supported by the German Science Foundation (DFG – Deutsche Forschungsgemeinschaft) under research grant BO2511/5-1.

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