Which Visualization Guides Learners Best? Impact of Available Partner- and Content-Related Information on Collaborative Learning

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Abstract: A large body of research covers the positive impact of cognitive group awareness tools on implicitly guiding learners. However, the impact of visualizing partner-related information and content-related information in such tools is barely investigated separately. Thus, we compared the impact of both types of information on collaborative learning in an experimental study (*N* = 120) by systematically varying partner-related information (given or not) and content-related information (given or not) in a 2x2 design. Concerning communication behavior, we found no effect of content-related information, but a main effect of partner information indicating that the visualization of a learning partner's knowledge deficit implicitly guides learners to give longer explanations. A qualitative comparison contrasting learners with the highest and lowest knowledge gain indicate that content-related information could still be relevant for implicit guidance, since successful learners seem to use this information for addressing topics in their explanations.

Introduction

The positive impact of implicit guidance on collaborative learning was widely demonstrated (cf. Janssen & Bodemer, 2013). Implicitly guiding learners means to only suggest them certain ways of thinking, communicating, and behaving, without directly instructing them to perform specific activities (cf. Hesse, 2007; Dillenbourg, 2002). Such guidance can be implemented with the help of cognitive group awareness tools. Following Bodemer and Scholvien (2014), these tools utilize three functions for suggesting specific behaviors: First, they can cue and list essential information, e.g. specific content, which helps learners to organize their knowledge and structure their communication with the learning partner. Second, they provide information on the whole group or single members of the group to facilitate important grounding and partner modeling processes. Third, they facilitate comparison processes to trigger discussions that are focused on relevant topics. In order to automatize these functions, the "Grouping and Representing Tool" (GRT) was developed (Erkens, Bodemer, & Hoppe, 2016). This tool extracts different information from written text (e.g. students' homework or essays): on the one hand, it transforms content-related information by forming clusters of concepts that are interpreted as topics and visualized as a list. On the other hand, it provides partner-related information, since the clustering results in quantitative values on the extent of how intensively these topics are debated in each text. These values can be visualized as bars per topic illustrating a learning partner's cognitive information separate or side-by-side with a learner's own cognitive information to facilitate a comparison, which is particularly useful in collaborative learning scenarios applying complementary group formation The GRT was evaluated beneficial for classroom learning (Erkens et al., 2016), but due to their confounding both types of information still need to be investigated separately to know about their single effects. Since said confounding is given for most group awareness tools, the current study is guided by the pending question: What and how much impact has partner- and content-related information on learning behavior? In the following, we present results from a current study combining quantitative and qualitative measures to answer this question.

Instructional purposes of cognitive group awareness tools

Cognitive group awareness tools fulfill several instructional purposes by providing learners with relevant cognitive information. Visualizations with content-related information can unfold their effects by information cueing (e.g. highlights) or by visualizing only selected information (e.g. topics). Information cueing refers back to the signaling principle which means that learners focus their attention and learn more deeply, when cues are added that highlight the organization of essential material (Mayer, 2005). In the context of collaborative learning, Scholvien and Bodemer (2013) found that learners supported by a cognitive group awareness tool prioritized content that was highlighted blue to reveal dissimilarities between them and their learning partner. Concerning the visualization of selected information, the effect of information clustering is based on the idea that visual representations that include organized labels, names, and graphics group relevant information (Hyerle, 2000), thereby focus learners' attention (Mayer, 1979) and provide better orientation, especially in cooperative learning scenarios (Purdom & Kromrey, 1992). Regarding this, Erkens, Bodemer and Hoppe (2016) found indicators that a list of contents created by the GRT might influence learners in selecting topics to be discussed: one observed strategy was that learners scanned the list of content to check for topics about which they did not write in their essays (independent of the information given on a learning partner's knowledge) and finally added concepts visualized to their essays.

The visualization of partner-related information, either visualized separately or side-by-side with the information of a learner, supports comparison processes. The comparison between learning partners is associated with relevant learning mechanisms such as partner modeling, conflict solution, and (self-)explication (Dillenbourg, 1999). The concept of cognitive conflict goes back to Piaget (1977) and is based on the idea that interactions with physical or social environments can lead to a disequilibrium. In the case of a partner model contradicting the model of a learner's own knowledge, intrapersonal (Piaget & Inhelder, 2008) or interpersonal cognitive conflicts (Doise & Mugny, 1984) might occur. A learner can solve such conflicts by selecting specific topics and discussing them with the learning partner. Bodemer and Scholvien (2014) found that learners provided with partner-related information by a group awareness tool search for and prioritize topics visualizing cognitive dissimilarities to their learning partners before discussing less relevant topics. The concept of explication can be associated with audience design which means that speakers design each utterance for specific listeners (Clark & Murphy, 1982). In the case of visualizations supporting learners to estimate their partner as less knowledgeable, they might explain more to this learning partner. Regarding this, Dehler, Bodemer, Buder, and Hesse (2011) found that learners supported by a comparative visualization of learners' own and their respective partner's knowledge explained more in a discussion than learners without support, when a learning partner's deficit was visualized.

Overall, we can summarize that the visualization of combined content- and partner-related information can determine learners' focus and induce them to explain more to a learning partner. However, while both types of learner support have been evaluated separately, they have not been tested yet in one experiment that allows for comparing the impact of both. Thus, it is our objective to separate content- from partner-related information and investigate their single effects on learning behavior exemplarily for the GRT. We can conclude from the above that learners knowing more than their learning partner give longer explanations, if partner-related information is given. Further, we could assume that this effect might be especially strong, if content-related information is also given, since this combination was used in most tools that showed an effect on explaining behavior. Further, it is plausible that a list of several sub topics might evoke more detailed explanations than only being aware of the main topic, since a summary of principal issues could remind learners of relevant aspects that might be forgotten while explaining without such support. However, Erkens, Schlottbom and Bodemer (2016) found that learners gave more explanations without the visualization of content-related information. So it is still an open question, if there is an interaction effect of both partner- and content-related information on the length of explanations. Finally, we ask, which visualization of the given information supports elaboration or rather selection of topics best.

Method

To conduct our laboratory experiment lasting one and a half hours we recruited a total of 120 university students (42 men; 78 women; mean age: $M = 23.84, SD = 4.40$). The participants were either paid 12 Euro, or received a certification on their contribution, and were randomized in a 2x2 factorial design to ensure evenly distributed knowledge on the topic to be learned prior to the collaboration (p = .71). As can be seen in Figure 1, we deployed four different visualizations to support the four groups during the collaboration: (1) one visualization neither displaying content- nor partner-related information, (2) another one displaying no content- but partner-related information, (3) one displaying content- but no partner-related information, and (4) one displaying both content- and partner-related information. Consistent with the GRT's functions, content-related information stands for displaying a list of topics (bold text listed in (3) and (4)) with related concepts (normal text listed in (3) and (4)) generated from the texts used in the study. Partner-related information stands for visualizing partner's topical extent(s) as a grey bar. Own topical extent(s) was visualized as black bar. Said topical extents (bars) were based on the knowledge that was imparted to the participants by a text on climate change.

As dependent variable, we captured communication behavior that was operationalized as the length of explanations given to a partner and we controlled for time of text re-reading as a covariate. Further, we qualitatively examined the behavior of particularly successful or unsuccessful learners more closely and contrasted the best and worst learner of the most contrasting experimental groups, (1) and (4), to learn more about the quality of explanations.

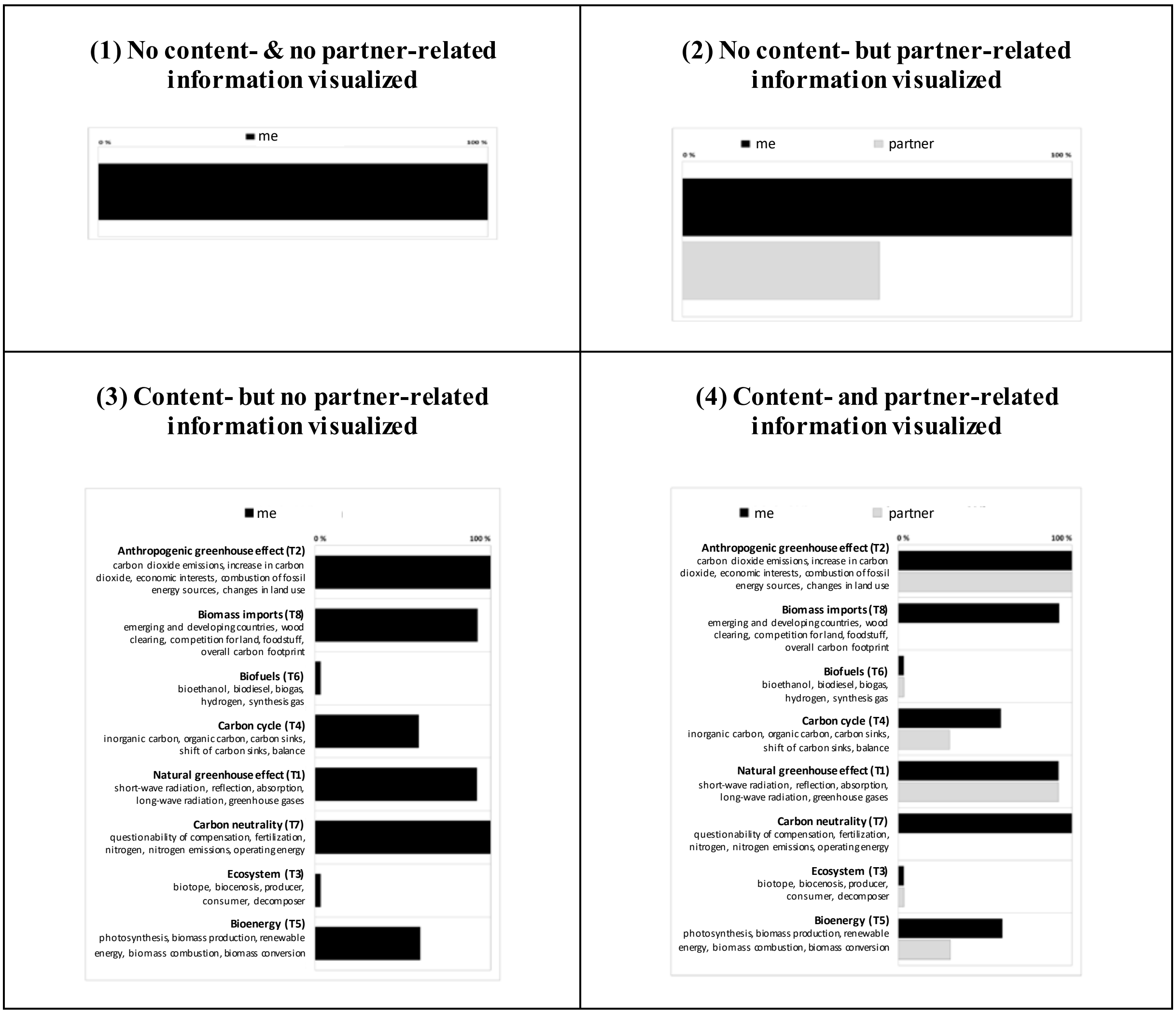

Figure 1. Four visualizations with different content- and partner-related information. Content-related information is given in (3) and (4) with topics in bold text and concepts in normal text. Partner-related information is given in (2) and (4) with the partner's knowledge visualized as grey bar(s).

Procedure and instructions

The idea of our study was to reconstruct a real collaborative scenario with learners asking and answering questions instead of triggering a real discussion in order to ensure controlled framework conditions. Although this article presents only results related to the phase of answering questions or rather explicating, we outline the whole procedure in the following (cf. Figure 2) for better comprehension. The experiment was conducted with each participant working on a single computer. After welcoming and declaration of consent, the participants were informed that they had to read and memorize a text on climate change within 15 minutes forming a basis for their later explanations and to simulate a collaboration with two other participants, of whose non genuine nature they were aware. Following a pre-test to evaluate their knowledge, they were instructed to ask their first learning partner (A) questions. During the simulated collaboration they were provided with a visualization illustrating a scenario in which they had less overall knowledge than their learning partner A (similar to Figure 1 but with other values or rather shorter bar lengths). The participants were supported by a representation showing their own knowledge status and visualizing (or not) a list of topics and main concepts presented in their own and

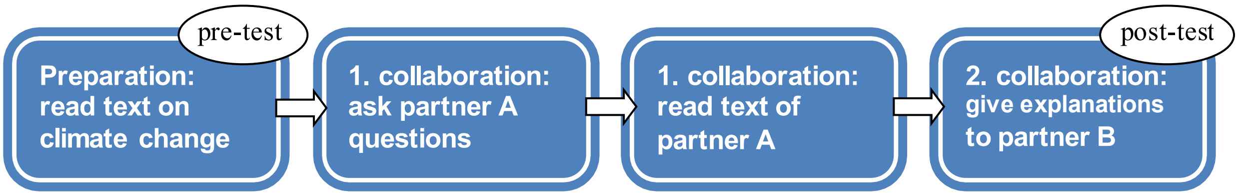

Figure 2. Graphical overview of the experiment's procedure.

their learning partner's text and visualizing (or not) bars that represent their learning partner's extent of knowledge allowing for comparison to the partner status. They should write down then a minimum of three questions as open text. After this first learning phase, they were informed that learning partner A had not the task to ask questions but to write a text about his knowledge on climate change and that they should carefully read this contribution within 10 minutes. Following this phase, participants were requested to give explanations to questions of their second learning partner (B) (cf. Figure 3) to simulate a discussion with a partner that might disclose a possible adaption to the available partner's knowledge. This time, the participants were supported by a visualization based on a scenario in which they had a higher overall knowledge than their learning partner B (cf. Figure 1), which means that they had the same availability of content- and partner-related information as in the first collaboration, but the lengths of bars was mainly longer in the respective visualization. The learning environment offered to make their contributions as open text again. Finally, participants had to take a post-test.

Instruments and variables

Length and topical scope of explanations

During the second collaboration, we presented the participants three questions of the bogus learning partner: (1) "What are the decisive advantages of energy from biomass against the background of global warming?", (2) "What are the decisive disadvantages of energy from biomass against the background of global warming?", and (3) "What are your conclusions regarding energy from biomass against the background of global warming?". Under each question, we presented the respective visualization on the left, a possibility to access the text on climate change on the right, and a scalable input window for answering the question with an explanation of any chosen length in the middle (cf. Figure 3). Subsequent to this bogus collaboration, we counted the number of words for each answer and cumulated them to calculate the total length of explanations. Further, the elaborations were investigated concerning included topics to contrast the best and worst learners in the experimental group with no visualization of content- and partner-related information and in the experimental group with partner- and content-related information given. Therefore, we counted the occurrences of each topic within the three explanations per participant and summed them up.

Time spent re-reading the text on climate change

On each of the three pages for answering the learning partner's questions, learners had the possibility to access the text on climate change (cf. Figure 3) and read it as long as they wanted. We herewith wanted to create a situation with all participants being able to fall back on the same content knowledge. We measured the time between opening and closing the text each time it was opened. Finally, we summed up all values per person to establish the total time of re-reading while explaining. We chose this total time as control variable, since it is probable that more time of re-reading the material might come along with less time for writing explanations, and might also be predictive for the length of explanations.

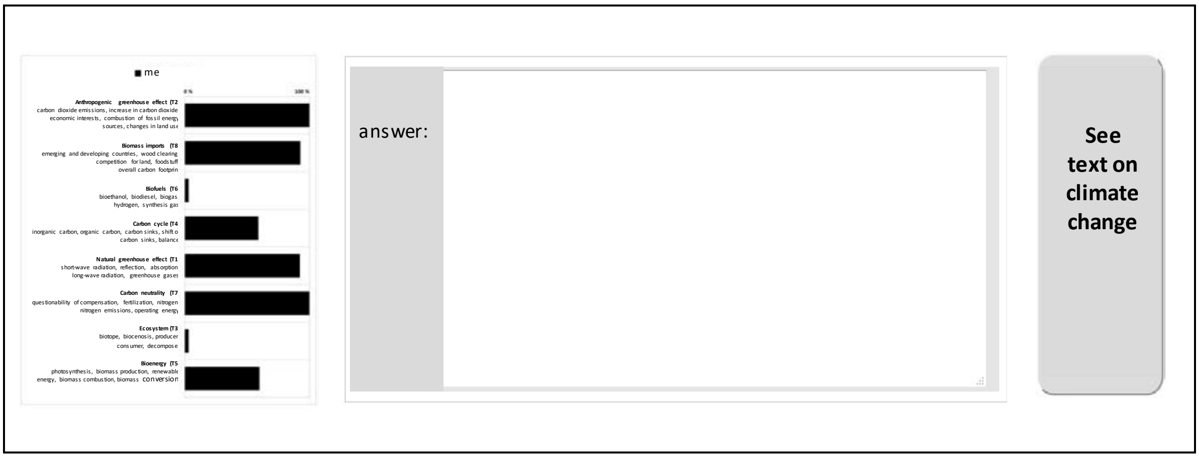

Figure 3. Participants' view on the learning environment during the collaboration.

Score of knowledge test pre and post the collaboration

The knowledge test consisted of 36 statements related to four topics in the text on climate change and to two topics of the first bogus learning partner's text. We presented the statements (e.g. "Photosynthesis ensures that plants gain energy to produce dead matter" or "The total carbon content of the earth is constant) prior to the collaboration (pre-test) and afterwards in randomly rotated order (post-test). Participants had to state whether the answer was true or false. In order to calculate the total score of the knowledge test, we checked for each item, whether the given answer was correct or not. Finally, we summed up all points for both times of measure (pre and post). Thus, both total scores could range from 0 to 36 points. They were needed to identify the learners with the highest and lowest knowledge gain in the different experimental groups.

Results

For answering the question of how partner- and content-related information affects learning behavior, we observed the impact of different visualizations on the length of explanations and on learning results. All effects are reported as significant at $p < .05$.

Impact of partner-related and content-related information on explanations

We hypothesized that learners supported by the visualization of partner-related information explain more about subject matters than learners without partner-related information. Further, we investigated if this effect is particularly strong, if additional information on the content is given. For investigating these assumptions, we used a two-factorial ANCOVA with availability of partner-related information and content-related information as between-subject factors and the number of total words in explanations per person as dependent variable. Further, we controlled for the time of re-reading the learning material to keep the prior knowledge constant across learners. This covariate was suitable to be included in the analysis, since it fulfilled all preconditions.

The covariate *re-reading time* was significantly related to the count of words in explanations, $F(1, 115) = 12.16$, $p < .001$, $\eta_p^2 = .096$. The longer the time of re-reading, the shorter the explanations. Regarding the assumption that available partner-related information triggers longer explanations, results indicated a significant main effect of partner information on the number of words used in explanations, $F(1, 115) = 3.97$, $p = .049$, $\eta_p^2 = .033$. Further, results yielded no significant main effect of content-related information on the number of words used in explanations, $F(1, 115) = 0.12$, $p = .725$, $\eta_p^2 = .001$. Finally, there was no interaction effect of partner- and content-related information on the number of words in explanations, $F(1, 115) = 0.13$, $p = .716$, $\eta_p^2 = .001$. Table 1 shows related descriptive statistics.

Table 1: Number of words in explanations

	content-related information given (n = 61)		content-related information not given (n = 59)		overall (N = 120)	
	M	*SD*	*M*	*SD*	*M*	*SD*
partner-related information given (n = 61)	256.00	95.05	249.90	78.07	253.00	86.45
partner-related information not given (n = 59)	225.03	98.65	224.97	85.75	225.00	91.74
overall (N = 120)	240.77	97.29	237.64	82.19	239.23	89.82

Contrasting cases: Comparison of successful and unsuccessful learners

To learn about the quality of elaborations, we examined the behavior of particularly successful or unsuccessful learners more closely and contrasted the best and worst learner of experimental group (1) with neither partner-related nor content-related information and experimental group (4) with both types of information available. Against the theoretical background, we assumed that the availability of content- and partner-related information might improve the selection of topics used in explanations, since the visualization of selected information from text should focus learners' attention and the scenario displaying the learning partner to be less knowledgeable might evoke deeper elaborations. To investigate whether learners in the experimental group with both awareness information available might be better supported concerning the selection of topics to be discussed than the group with less information, our special interest were the matches between knowledge test items that learners improved from pre- to post-test and the topics used in their explanations. We observed, how often they were related to each other in two ways of matches: (a) topics addressed within explanations (T1 to T8) did match topics addressed in knowledge test items (topical matches), and (b) concepts addressed within explanations did match concepts addressed in knowledge test items (conceptual matches). In Table 2, you can see an overview of our findings including knowledge gain and information on improvements and worsening.

Table 2: Characteristics of learners in contrasting cases.

	(1) No content- & no partner-related information visualized		**(4) Content- and partner-related information visualized**	
	learner ID 102	*learner ID 27*	*learner ID 3*	*learner ID 62*
score pre-test[1]	26	18	22	24
score post-test[1]	19	26	18	29
knowledge gain	-7	+8	-4	+5
# improvements	2	8	5	5
# worsening	9	0	9	0
improved topics from pre- to post-test	$T2_{(1x)}$, $T7_{(1x)}$	$T1_{(2x)}$, $T2_{(2x)}$, $T5_{(2x)}$, $T7_{(1x)}$, $T8_{(1x)}$	$T2_{(3x)}$, $T4_{(1x)}$, $T5_{(1x)}$	$T1_{(1x)}$, $T2_{(1x)}$, $T5_{(2x)}$, $T7_{(1x)}$
worsened topics from pre- to post-test	$T1_{(1x)}$, $T2_{(2x)}$, $T4_{(2x)}$, $T5_{(1x)}$, $T7_{(1x)}$, $T8_{(2x)}$	-	$T1_{(1x)}$, $T4_{(1x)}$, $T5_{(2x)}$, $T7_{(1x)}$, $T8_{(3x)}$	-
# topical matches	2	5	1	4
# conceptual matches	0	1	0	3

T_x = topic (cf. Figure 1). Numbers in brackets = count of occurrences. [1]scoring from 0-36.

Comparison of the best and worst learner without content and partner information

To contrast cases in the experimental group in which learners had neither partner-related nor content-related information we chose the learner with the highest and the lowest knowledge gain in the knowledge test. We found that learner 27, who improved her/his score by 8 points, showed a huge amount of topical matches. In five cases she/he wrote about topics having errors in the pre-test, but only in one case the concept was actually congruent: Concerning the test item "The chemical transformation of carbonaceous compounds runs completely independent of the nitrogen cycle." (which is wrong, since both cycles depend on each other), learner 27 who checked this answer as "right" in the pre-test explained in the second collaboration to her/his learning partner: "I do not consider this [generating energy from biomass] as beneficial, if the cultivation and growing of biomass entails the warming of the atmosphere caused by nitrogen und carbon dioxide." Thus, she/he understood that both nitrogen and carbon cycle interact in the context of global warming. In contrast to learner 27 with the highest improvements in this experimental group, learner 102 dropped off 7 points in the score of the post-test or to be more precise she/he dropped 9 points and gained 2 points. In this case, the learner wrote about 5 topics that were improved from pre- to post-test, but the concepts did not match to concepts in the improved test items. To give an example: Learner 27 stated "Likewise, during the production of biomass, dead matter is bound and decreases in the atmosphere…" what is part of topic 4 (concept: dead matter) and topic 5 (concept: biomass production). On the one hand, this utterance is wrong, since it is CO_2 that is bound and reduced in the atmosphere. On the other hand, the concept does not match the concepts of the improved items in the post-test that instead were related to the topics T1, T5 and T7. Thus, learner 102 seemed to decrease her/his knowledge caused by misconceptions that emerged during the explanation process.

Comparison of the best and worst learners with content and partner information

In this case, we contrasted the best and the worst learner with a visualization available that combines partner- and content-related information. We found that learner 3, who dropped off 4 points from pre- to post-test, had no matches of concepts in his/her explanation and concepts in the test items, only once a topical match was given. In contrast, we found that learner 62 who improved his/her score by 5 points had a good topical match between test items and explanations. She/he met 4 times the topical scope of test items and even though mentioned 3 times concepts in her/his explanations that were part of improved test items. For instance, learner 62 scored better at the test item "The photosynthesis enables plants to produce energy and dead matter" (which is wrong, since the plant produces organic matter). Accordingly, she/he explained to his/her learning partner "Renewable energy using biomass is energy that stems from non-fossil algal or vegetable biomass." and "Biomass first needs to be produced by photosynthesis". Both utterances show that she/he understood that photosynthesis does not produce dead matter. Precisely because learner 62 improved his/her knowledge after giving explanations to the learning partner, it is noteworthy how the learners evaluated the visualization in an open question following the collaboration: while learner 3 reported that she/he used the visualization "partially" which is in line with his/her behavior, learner 62 reported that the "visualization was not helpful to answer the questions". However, from the five improvements of learner 62 (in T1, T2, 2xT5, T7), she/he consequently gave only explanations when it was displayed that she/he is more knowledgeable than her/his learning partner (in T5 and T7). Since she/he further reported that she/he used the visualization to scan for cases in which his/her knowledge was displayed being less than the learning partner's knowledge and to ask questions exactly in this, we can assume that she/he (implicitly) did the same concerning explanations (although described differently by learner 62).

Conclusion

We conducted this empirical study to systematically investigate the impact of partner- and content-related information on collaborative learning, or rather on explaining behavior and on the selection of topics to be discussed. Consistent with previous research (Dehler et al., 2011) we found that the visualization of partner-related information implicitly guides learners' communication behavior and makes them give longer explanations if they are more knowledgeable than their learning partner. In contrast, content-related information that is inherent to most such tools seem to have no effect on adapting explanations to the learning partner's knowledge in terms of explaining more to a less knowledgeable learning partner. Erkens, Schlottbom, and Bodemer (2016) assumed that too many topics might overstrain learners' cognitive system. Further, visualizing partner-related information without content-related information might suggest learners assuming the role of an expert and explaining as much as possible. Both these assumptions need to be further investigated. Also it is still unclear, whether shorter explanations could nevertheless show a better quality. Learners supported by the visualization of both partner- and content-related information might better elaborate the contributions of a learning partner than learners without this support, since their prior knowledge could be better activated. After all, activation of prior knowledge is known as the most important antecedent for learning (Glasersfeld, 1984; Resnick, 1983; Ausubel, 1960), since it supports learners to successfully add new concepts learned from the partner to the existing knowledge base. Finally, learners only provided with content-related information are most likely unable to precisely detect their learning partner's knowledge gaps and might thus not adapt their behavior to the knowledge of their learning partner.

In a second step, we investigated qualitatively how improvements from pre- to post-test were supported by implicit guidance. Here, our focus was on the usage of given information to explain learners' improvements. We found that successful learners across experimental groups frequently discussed relevant topics, while unsuccessful learners did not discuss such topics. But only the successful learner provided with partner- and content-related information also wrote more often about concepts relevant to get better in a test item than the successful learner with none of this information. Based on this, we can first assume that content-related information might have helped to be reminded of concepts relevant to understand a topic. Thus, displaying content-related information still seems to be helpful to implicitly guide the learner in terms of influencing learning behavior. Although said learner mentioned that the visualization was not needed for answering questions, we further found that this learner especially explained relevant topics, when it was displayed that she/he is more knowledgeable than her/his learning partner (in T5 and T7). Thus, we can further assume that partner-related information might have helped her/him to select topics to be discussed. However, both these aforementioned assumptions were not captured with the length of explanations and further qualitative research is needed to tell more about the quality of elaborations within the explanations.

Overall, the support by visualized partner- and content-related information seems to fulfil different functions. Partner-related information leads to longer and possibly more detailed explanation. Concerning the role of content-related information, we have to further investigate whether their visualization influences the quality of explanations by activating prior knowledge or by determining the selection of topics. This research might offer answers on how to appoint cognitive information in a task-oriented way and on how to even better support collaborative learning processes.

References

Ausubel, D. P. (1960). The use of advance organizers in the learning and retention of meaningful verbal material. *Journal of Educational Psychology*, *51*(5), 267–272. https://doi.org/10.1037/h0046669

Bodemer, D., & Scholvien, A. (2014). Providing knowledge-related partner information in collaborative multimedia learning: Isolating the core of cognitive group awareness tools. In *Proceedings of the 22nd International Conference on Computers in Education ICCE 2014* (pp. 171–179). Nara, Japan.

Clark, H. H., & Murphy, G. L. (1982). Audience design in meaning and reference. In *Advances in Psychology* (Vol. 9, pp. 287–299). Elsevier. Retrieved from http://linkinghub.elsevier.com/retrieve/pii/S0166411509600595

Dehler, J., Bodemer, D., Buder, J., & Hesse, F. W. (2011). Guiding knowledge communication in CSCL via group knowledge awareness. *Computers in Human Behavior*, *27*(3), 1068–1078. https://doi.org/10.1016/j.chb.2010.05.018

Dillenbourg, P. (1999). What do you mean by collaborative learning? *Collaborative-Learning: Cognitive and Computational Approaches*, 1–19.

Dillenbourg, P. (2002). Over-scripting CSCL: The risks of blending collaborative learning with instructional design. *Three Worlds of CSCL. Can We Support CSCL?*, 61–91.

Doise, W., & Mugny, G. (1984). *The social development of the intellect*. (W. Doise & G. Mugny, Eds.) (Vol. 10). Amsterdam, Netherlands: Pergamon. Retrieved from http://www.sciencedirect.com/science/article/pii/B978008030215750010X

Erkens, M., Bodemer, D., & Hoppe, H. U. (2016). Improving collaborative learning in the classroom: text mining based grouping and representing. https://doi.org/10.1007/s11412-016-9243-5

Erkens, M., Schlottbom, P., & Bodemer, D. (2016). Qualitative and quantitative information in cognitive group awareness tools: Impact on collaborative learning. In U. Cress (Ed.), *Transforming Learning, Empowering Learners: The International Conference of the Learning Sciences (ICLS) 2016*. Singapore: International Society of the Learning Sciences.

Glasersfeld, E. v. (1984). An introduction to radical constructivism. In P. Watzlawick, (Ed.), *The invented reality*. New York, NY: W.W. Norton.

Hesse, F. W. (2007). Being told to do something or just being aware of something? An alternative approach to scripting in CSCL. In *Scripting computer-supported collaborative learning* (pp. 91–98). Springer. Retrieved from http://link.springer.com/chapter/10.1007/978-0-387-36949-5_6

Hyerle. (2000). *A Field Guide to Using Visual Tools*. Alexandria, Va: Association for Supervision & Curriculum Deve.

Janssen, J., & Bodemer, D. (2013). Coordinated computer-supported collaborative learning: Awareness and awareness tools. *Educational Psychologist*, *48*(1), 40–55.

Mayer, R. E. (1979). Twenty years of research on advance organizers. Technical report series in learning and cognition. Report No. 79-1. Retrieved from http://eric.ed.gov/?q=Mayer+advance+organizer&id=ED206691

Mayer, R. E. (2005). *The Cambridge Handbook of Multimedia Learning: Principles for Reducing Extraneous Processing in Multimedia Learning : Coherence, Signaling, Redundancy, Spatial Contiguity, and Temporal Contiguity Principles*. Retrieved from /chapter.jsf?bid=CBO9780511816819A020&cid=CBO9780511816819A020

Piaget, J. (1977). *The development of thought: equilibration of cognitive structures*. Viking Press.

Piaget, J., & Inhelder, B. (2008). *The psychology of the child*. New York, NY: Basic Books.

Purdom, D. M., & Kromrey, J. D. (1992). A comparison of different instructor intervention strategies in cooperative learning groups at the college level. Retrieved from http://eric.ed.gov/?id=ED344898

Resnick, L. B. (1983). Mathematics and science learning: A new conception. *Science*, *220*(4596), 477–478. https://doi.org/10.1126/science.220.4596.477

Scholvien, A., & Bodemer, D. (2013). Information cueing in collaborative multimedia learning. In N. Rummel, M. Kapur, M. Nathan, & S. Puntambekar (Eds.), *To See the World and a Grain of Sand: Learning across Levels of Space, Time, and Scale: CSCL 2013 Conference Proceedings Volume 2 — Short Papers, Panels, Posters, Demos & Community Events* (Vol. 2, pp. 149–152). Madison, WI.