Effects of Knowledge Interdependence with the Partner on Visual and Action Transactivity in Collaborative Concept Mapping

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Abstract: In the present study, participants working in dyads were asked to build a concept map collaboratively. While interacting, they were able to access visualizations (individual concept maps) of both their own and their partner's prior knowledge (own and peer maps). Eye movements of both learning partners were recorded during the course of collaboration. Our goal was twofold. First, we focused on transactivity at both the visual and action levels. Second, we investigated the effects of knowledge interdependence with the partner on transactivity in collaborative concept mapping. We found that the degree to which participants co-manipulate the same objects in the collaborative map (action transactivity) is higher when they discussed identical (rather than complementary) information. Results from eye-gaze data showed that participants who shared complementary information transitioned more frequently between their own map and their partner's map; eye-movement transitions between own and peer maps were also negatively correlated with learning outcomes.

Research background

The aim of the present study was to extend CSCL studies dealing with intersubjective meaning making (Suthers, 2006a) through shared external representations (e.g., Engelmann & Tergan, 2007; Fischer, Bruhn, Gräsel, & Mandl, 2002; Lund, Molinari, Séjourné, & Baker, 2007; Suthers, 2006b; Schwartz, 1995).

Our goal was twofold. First, we wanted to deepen our knowledge of how students – working in dyads – construct a common concept map in order to graphically represent their shared understanding of a particular learning topic (the functioning of the neuron). More specifically, we focused on transactivity in collaborative concept mapping. In this study, while building together the concept map, learners were able to access visualizations (individual concept maps) of both their own prior knowledge and their partner's prior knowledge. In addition, thanks to two synchronized eye-tracking devices, eye movements of both learning partners were recorded during the course of interaction. Results reported here concern transactivity at both the visual and action levels. We studied how learners distributed their eye gaze among the three different visualizations (collaborative, own and peer concept maps). In particular, we examined the extent to which participants visually referred to their partner's prior knowledge during collaboration (visual transactivity). At the action level, transactivity was analyzed as being the extent to which participants operate on concept map objects built or recently modified by their partner. Second, we aimed at investigating the effect of a macro-collaborative script (i.e., a sub-class of jigsaw scripts; see Dillenbourg & Jermann, 2006; Dillenbourg & Tchounikine, 2007) designed to produce knowledge interdependence among partners (see Buchs & Butera, 2001; Buchs, Butera & Mugny, 2004), on transactivity. In the present study, before collaboration, either both partners were provided with the same prior knowledge on the studied topic ("same information" or SI condition), or each partner was assigned to one part of knowledge ("complementary information" or CI condition). We wondered to what extent discussing on complementary information might affect the degree to which participants (visually) refer and build on each other's contributions.

Collaborative concept mapping and transactivity

Concept mapping is a technique allowing to provide an external representation of relationships between concepts relative to a particular topic. For Novak (1990), building a concept map reflects a constructivist view of learning: Deep understanding consists in building meaningful links among concepts and also in incorporating newly learned concepts into the learners' existing knowledge base (Glaser & Bassok, 1989; Molinari & Tapiero, 2007). The effectiveness of concept maps in promoting individual acquisition of knowledge is recognized (for science learning, see e.g., Stoddart, Abrams, Gasper, & Canaday, 2000). In addition, the conversion of information from one semiotic register (a textual representation) to another (a graphical representation) has been claimed to have a positive impact on learning (see e.g., Lund et al., 2007). Using concept maps as a means for interacting also can be viewed as an efficient way for facilitating intersubjective knowledge construction (e.g., Fischer et al., 2002; Lund et al., 2007; Suthers, 2006a, 2006b). Benefits of visualization tools for collaboration are multiple. They may promote the emergence of a more abstract solution to a problem (Fischer et al., 2002; Schwartz, 1995). They also support the negotiation process – e.g., both partners must reach an agreement for actions (creation, modification or deletion of concepts or links) to perform in the collaborative map (Suthers, 2003). Moreover, interactions through a concept map make visible differences in knowledge and points of view between learners. Engelmann and Tergan (2007) found that learners benefit from the availability of a graphical representation (individual map) of their partners' prior knowledge during the course of interaction: participants collaborated together more effectively when they were provided with both their own- and their partners' map (experimental condition) than when they could see only their own map (control condition).

Our interest in studying collaborative concept mapping lies in the question of how learners "refer to", "do something with" or "build upon" their partner's contributions (otherwise known as *transactivity*; Teasley, 1997) in the common concept map. Transactivity is usually investigated in discourse (Berkowitz & Gibbs, 1983; Joshi & Rosé, to appear; Teasley, 1997), and different degrees of transactivity are distinguished (Fischer et al., 2002; Teasley, 1997; Weinberger, Stegmann, & Fischer, 2007), namely (1) externalization, (2) elicitation, (3) quick consensus, and (4) integration/conflict-oriented consensus building. Externalization occurs when partners exchange their private knowledge. Elicitation is when learners seek information by questioning their partner. A quick consensus is built when learners (implicitly or explicitly) accept – without negotiation – their partner's contributions usually in order to pursue the conversation. Integration- or conflict-oriented consensus building is viewed as the highest mode of co-construction: a joint decision is made as a result of a dynamic incorporation of both agreements and disagreements between partners (Matusov, 1996). Studies on transactivity in discourse have provided evidence of its positive impact on collaborative knowledge construction (Teasley, 1997). To our knowledge, only Suthers (2006b) studied transactivity in collaboration through graphical representations. The method he proposed to investigate knowledge construction activity through shared external representations (the uptake graph) is based on the identification of what he called the "intersubjective uptake acts". Uptake acts can be defined as manipulations of the partner's contributions (or co-manipulations) such as for example, building links between concepts previously created by the partner, referring to the partner's concepts or rewording them. Suthers (2006b) suggested that "grounding by implicit uptake of the interlocutor's actions" would be a crucial process for intersubjective meaning making.

Knowledge interdependence with the partner

Our second goal was to investigate the effects of knowledge interdependence with the partner on transactivity in collaborative concept mapping. In our study, the collaboration was preceded by an individual reading phase aiming at providing participants with specific knowledge about the learning topic. Two conditions were compared. Peers were assigned to the reading of different but complementary texts about the neuron in the "complementary information" (CI) condition, whereas they studied the same text in the "same information" (SI) condition. Two alternative hypotheses are usually stated in the literature with respect to the effects of knowledge in(ter)dependence in collaborative learning (Buchs & Butera, 2001; Buchs et al, 2004). The first one assumes that working on identical information (independent condition) would promote the confrontation of different perspectives (e.g., different understanding of the same information) considered as a potential source for learning (Doise & Mugny, 1984). The second one assumes that learning partners would benefit more from sharing complementary information (see e.g., Lambiotte et al., 1987): in a dependent condition, (a) the likelihood of competence evaluation would be reduced and more attention would be allocated to content, (b) decentration and perspective-taking would be promoted. Buchs et al. (2004) found that the effects of knowledge interdependence on collaborative learning depend on the difficulty of complementary texts (text complexity seems to impair the quality of explanations generated during interaction). In Buchs et al.'s (2004) study 2 (in which easier texts were used), there was no difference in immediate learning performance between the independent and dependent conditions, whereas a positive effect of discussing complementary information was obtained on a delayed test.

Research questions

Following Suthers (2006b), we hypothesize that transactivity in collaborative concept mapping would operate at three communicative levels, that is, the visual, action and discourse levels. Results reported in this paper concern transactivity only at the visual and action levels. We examine the following questions:

1. To what extent do participants visually refer to their partner's prior knowledge (the partner's individual concept map) while building the collaborative concept map (visual transactivity)?
2. To what extent do participants manipulate their partner's contributions (intersubjective uptake acts) in the collaborative map (action transactivity)?
3. To what extent does transactivity at both the visual and action levels influence (a) individual learning and also (b) equivalence between learning partners regarding the extent of their outcome knowledge (see Weinberger et al., 2007)?

Based on Buchs et al.'s (2001, 2004) studies, we hypothesize that knowledge interdependence with the partner would impact the degree to which participants (visually) focus on their partner's prior knowledge (visual transactivity) and also build on their partner's contributions in the collaborative map (action transactivity). Our research questions are as follows:

4. To what extent does a computer-supported script designed to create knowledge interdependence among co-learners influence both individual acquisition of knowledge and outcome knowledge equivalence?
5. To what extent does knowledge interdependence influence (a) the amount of time participants spent looking at their partner's individual concept map (visual transactivity) and (b) the number of uptake acts during the building of the collaborative concept map (action transactivity)?

Method

Participants and design

Fifty-eight first year students from our university, 47 men and 11 women, with a mean age of 20.46 (*SD* = 3.58) were remunerated for participation. All the participants were French-speaking, and had normal or corrected vision. In this experiment, the majority of participants were men, which reflects the distribution of students in the EPFL, but the mean/women ratio was equivalent in each condition.

The participants were paired into 29 dyads combining students from different schools (e.g., physics, microengineering, computer science, chemistry). Participants did not know each other before the experiment. Students from the School of life sciences were not recruited since they had significant background knowledge on the learning domain (i.e., the functioning of the neuron). Dyads were randomly assigned to one of the two experimental conditions: the "same information" (SI) condition (15 pairs) and the "complementary condition" (CI) (14 pairs). The difference between these conditions concerned the first phase of the experiment, when participants had to read a text individually: in the CI condition, peers were provided with different but complementary learning texts whereas they were asked to read the same text in the SI condition.

Learning material

Students in all conditions had to learn about the scientific domain of the neuron. This experiment consisted of four phases: (1) Reading individually a text about the neuron, (2) individual construction of a concept map (using the CmapTools application) in order to graphically represent what they learnt from the text, (3) collaborative construction of a concept map on the same learning topic with the same tool, (4) individual post-test questionnaire measuring their knowledge about the neuron.

Learning text

Understanding how the neuron works requires a basic understanding of the interplay between two coupled processes, that is, the flow of chemical ions and electrical charges. When the neuron is at rest, it is negatively charged. When stimulation occurs, positive ions flow into it and this negative charge decreases. An electric signal called "action potential" is produced that moves along the axon and induces the release of chemical neurotransmitters at the neuron's synaptic connections. These neurotransmitters flow across the synaptic space to receptors in the dendrites of adjacent neurons, changing their electro-chemical balance and making them more or less likely to fire. Thus, learning about the neuron's functioning involves the integration – into a unified mental representation – of two models of the neuron, an electrical model and a chemical model.

A text describing functionally the neuron was constructed and validated by two experts (a neurobiology researcher and a biology teacher) on the domain. It included three parts: (1) the resting membrane potential (resting potential part), (2) the initiation of the action potential (action potential part), (3) the propagation of the action potential and the synaptic transmission (transmission part). This learning text is an integrated view of both electric and ionic characteristics of the neuron.

In the SI condition, the learning text was read by both partners, while it was divided into two (shorter) sub-texts for the CI condition. One sub-text contained information regarding the electric aspects of the neuron's functioning (electric version) while the other sub-text included only the description of the chemical model (ionic version). Both sub-texts were also composed of three parts – the resting potential part, the action potential part and the transmission part. These two versions were equivalents in terms of number of information elements.

Learning questionnaire

After collaboration, all participants were invited to individually complete a questionnaire designed to assess the knowledge they acquired with regards to both the electrical and chemical models of the neuron. This test was composed of 18 questions (6 multiple-choice questions and 12 inference verification questions), 6 questions (3 electric and 3 ionic) per phenomenon (i.e., resting potential, action potential and transmission). The multiple-choice questions included four possibilities with 1 or more possible correct answers. The minimum score for these items was 0 and the maximum 4. The inference verification items consisted of either true (score of 0) or false (score of 1) assertions. The overall score for the knowledge test ranged from 0 to 36 (0 to 12 for each text part). All questions were validated by the experts and their variability was tested in a pilot study (questions with extremely low or high performance were eliminated; all the items used in the knowledge test were thus medium difficulty). The 18 questions were presented to all participants in a random order.

Collaboration environment

Participants were seated in two different rooms. Each room was equipped with a non-invasive Tobii 1750 binocular eyetracker integrated into a 17’’ screen and connected to a computer. Eye-movements of both partners were recorded during the collaborative phase. Gaze calibration was performed immediately before it. The screen activity during the collaboration phase was also captured.

Participants used two software components, CmapTools and TeamSpeak. The CmapTools environment was developed at the Institute for Human and Machine Cognition (http://cmap.ihmc.us/): it allows people to represent individually or collaboratively their (shared) knowledge using concept maps (Cañas et al., 2004). Practical advantages of the CmapTools system are that (a) it can be learned in few minutes; (b) due to its simplicity, users focus only on the construction of their concept map(s); (c) all map components (boxes, links and linking phrases) can be created rapidly (e.g., a double-click anywhere on the map for adding a concept); (d) it is synchronous. TeamSpeak enables participants to speak with each other (http://www.goteamspeak.com/). The participants’ interactions through the CmapTools software and the audio data were recorded.

During collaboration, the screen layout showed three functional areas (see Figure 1). The left hand side part was devoted to the construction of the collaborative map. The right half was divided horizontally into the two maps produced individually, their own map (above) and their partner’s map (below). Participants could scroll (either vertically or horizontally) both their own map and their partner’s map. They were also instructed (a) not to change the position of the three maps and (b) not to cut and paste parts of their own map or of their partner’s map into the collaborative map.

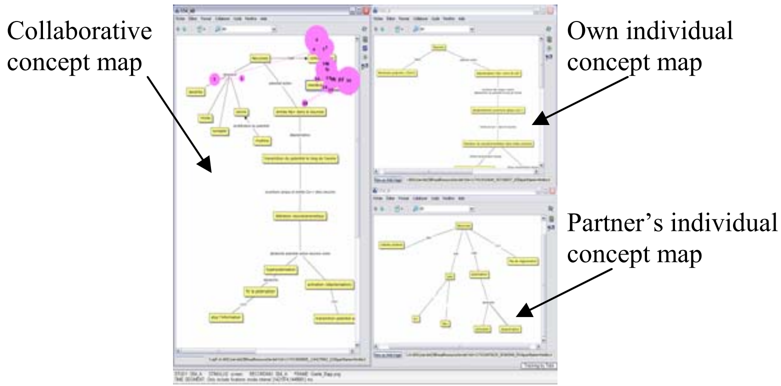

Figure 1. Collaborative phase.

Procedure

The procedure of the study included (1) a 12 minute reading phase, (2) the building of the individual concept map (10 minutes), (3) a collaborative phase of 20 minutes, in which peers constructed a common concept map, and (4) a knowledge post-test lasting 15 minutes. During the reading phase, participants could access at any time the content of any of the three sections of the text (i.e., resting potential, action potential, and transmission of action potential) by clicking on the “Module 1”, “Module 2” or “Module 3” button. No constraint was imposed concerning the order in which these three sections should be read. In addition, they were free to divide the reading time (12 min) between the three parts as seems best.

Variables

The sharedness of information between learning partners [complementary information (CI) texts versus same information (SI) texts] was the between-pairs variable.

The dependent variables were (a) *learning measures* and (b) *process variables*. Two learning measures were used: (1) a (individual level) measure of individual acquisition of knowledge obtained on the basis of the learning questionnaire completed after collaboration, and (b) a (dyad level) measure of outcome knowledge equivalence between peers that reflects the extent to which participants become similar to their partner with respect to their knowledge level (Weinberger et al., 2007a). We followed the method proposed by Weinberger et al. (2007b) to calculate knowledge equivalence (a coefficient of variation – defined as the standard deviation of a group divided by the group mean – was computed for each dyad).

Several *process variables* were computed to measure degree of both visual and action transactivity for each participant of each dyad. Regarding transactivity at the visual level, two sets of continuous variables were defined to reflect eye-movements on the three concept maps (i.e., the collaborative map, the own individual map and the partner’s individual map):

1. *Concept-map fixation time ratio*. We analyzed which concept map participants were looking at, that is, their own map, their partner's map or their common map. A tolerance zone of 10 pixels was added around each map area in order to take the eye-tracker's error into account. Then, we summed the fixation durations for each map separately and also for all fixations disregarding their position. This gave us a total fixation time for the whole experiment and one fixation time for each concept map. Using these values, we computed a ratio of fixation time spent on each map according to the whole fixation time.
2. *Number of concept-map eye-gaze transitions*. The number of times eye gaze of one participant shifts from any map to any other were counted. Six measures were obtained, one for each possible eye-gaze transition between the 3 maps (from collaborative map to own map and vice-versa, from collaborative map to peer map and vice-versa, from own map to peer map and vice-versa).

In addition, at the action level, we measured transactivity for each meaningful action (i.e. creation / modification / deletion of concepts / links). We computed to which extent an object "belongs" to one participant or to the other. This value was dynamically recalculated after each action. By using this "belonging" level, we were also able to estimate for each action the level of transactivity by comparing the user who did the action to the current "belonging" level. The more an object belongs to a given user, the more an action done by the other user on this object is transactive. We averaged the transactivity level of each action of one participant over the whole experiment in order to compute the global transactivity level for this participant.

Due to technical problems (low quality of eye-gaze data or recording problems), the statistical analyses were performed on data from 15 dyads (8 dyads for the SI condition and 7 dyads for the CI condition). An alpha level of .05 was used for all statistical tests on mean differences.

Results

Learning outcomes

Table 1 shows that at the individual level, learning performance was higher in the "same information" (SI) condition than in the "complementary information" (CI) condition ($t(28) = 2.10$, $p = .05$, $d = 0.78$).

At the dyad level, measure of outcome knowledge equivalence indicated that participants benefit more equally from learning together in the SI than in the CI conditions ($t(13) = -2.76$, $p = .01$, $d = 1.45$) (see Table 1).

Table 1: Individual learning performance and outcome knowledge equivalence in the two learning conditions.

	Individual learning (questionnaire)		Outcome knowledge equivalence	
	M	*SD*	*M*	*SD*
SI condition	17.88	3.24	0.07	0.03
CI condition	14.50	5.18	0.24	0.17

Note. Smaller mean values indicate knowledge equivalence.

Transactivity: Gaze data

Concept map fixation time ratio

Table 2 showed that participants focused twice longer on their own individual concept map in the CI condition than in the SI condition ($t(27) = -4.34$, $p < .01$, $d = 1.61$). There was no significant difference between the two conditions regarding fixation time on both the collaborative map ($t(27) = 1.53$, $p = .14$, $d = 0.57$) and the partner's individual map ($t(27) = 0.81$, $p = .42$; $d = 0.30$).

Table 2: Fixation time for each concept map (collaborative, own, peer) in the two learning conditions.

	Time on common map		Time on own map		Time on peer map	
	M	*SD*	*M*	*SD*	*M*	*SD*
SI condition	.71	.12	.08	.04	.14	.08
CI condition	.65	.09	.17	.06	.12	.05

Concept map eye-gaze transitions

Table 3 shows that eye-gaze transitions from the own map to the peer's map (and vice-versa) were twice more frequent in the CI condition than in the SI condition ("own to peer" transitions: $t(27) = -2.35$, $p = .03$, $d = 0.87$; "peer to own" transitions: $t(27) = -2.70$, $p = .01$, $d = 1.00$). In addition, participants produced more eye-gaze transitions from their individual own map to their collaborative map (and vice-versa) in the CI condition than in the SI condition; for "own to collaborative" and "collaborative to own" transitions, $t(27) = -2.71$, $p = .01$, $d = 0.99$ and $t(27) = -2.60$, $p = .02$, $d = 0.96$, respectively.

No difference occurred between the two conditions regarding eye-gaze transitions from individual peer map to collaborative map ($t(27) = 0.58$, $p = .57$, $d = 0.21$) and vice-versa ($t(27) = 0.46$, $p = .65$, $d = 0.17$).

Table 3: Eye-gaze shifts between the 3 concept maps (collaborative, own, peer) in the two learning conditions.

	Own to Collaborative		Collaborative to Own		Peer to Collaborative		Collaborative to Peer		Own to Peer		Peer to Own	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
SI	30.47	22.44	31.00	21.99	38.13	34.68	37.00	34.84	14.60	13.78	14.13	13.37
CI	61.93	38.59	61.29	39.02	32.14	19.82	32.07	21.91	26.86	14.35	27.14	12.53

Transactivity at the action level

We found that the global level of action transactivity was marginally higher in the SI condition ($M = 0.24$, $SD = 0.15$) than in the CI condition ($M = 0.14$, $SD = 0.14$) ($t(28) = 1.79$, $p = .08$, $d = 0.65$).

Correlational analyses

Relations (Pearson correlation coefficients) between learning outcomes, action transactivity and – (a) fixation time on collaborative, own and peer maps are displayed in Table 4, – (b) eye-gaze transitions (own-collaborative, collaborative-own, peer-collaborative, collaborative-peer, own-peer, peer-own) are displayed in Table 5. Correlations were computed at either (a) the individual level ($N = 30$) or (b) the dyad level ($N = 15$) to examine relations between process variables and (a) individual learning or (b) outcome knowledge equivalence.

Table 4 shows that at the individual level, learning was negatively correlated with fixation time on own individual map. In other words, the more participants were focused on their own map, the less they learnt. At the dyad level, the higher the group learning performance, the higher the equivalence between partners with respect to the extent of their outcome knowledge. In addition, higher outcome knowledge equivalence was associated with (a) higher fixation time on the collaborative map and (b) lower fixation time on the own map.

Table 4: Relationships between learning, action transactivity and fixation time on concept maps.

	2	3	4	5	6
1. Individual learning	-.54, $p = .04$	*NS*	*NS*	-.50, $p < .01$	*NS*
2. Knowledge equivalence		*NS*	-.60, $p = .02$	.72, $p < .01$	*NS*
3. Action transactivity			*NS*	*NS*	*NS*
4. Time on collaborative map				-.77, $p < .01$	-.78, $p < .01$
5. Time on own map					*NS*
6. Time on peer map					

Note. *NS* for non-significant.

Table 5 shows that at the individual level, learning performance was negatively correlated with "own-collaborative", "collaborative-own" and "own-peer" eye-gaze transitions. At the group level, we observed that the more frequently participants transitioned from their own map to their partner's map (and vice-versa), the lower was their knowledge level equivalence with their partner.

Table 5: Relationships between learning, action transactivity and eye-gaze transitions on concept maps.

	2	3	4	5	6	7	8	9
1. Individual learning	-.54, $p = .04$	*NS*	-.39, $p = .04$	*NS*	-.43, $p = .02$	*NS*	*NS*	-.42, $p = .02$
2. Knowledge equivalence		*NS*	*NS*	*NS*	*NS*	.64, $p = .01$	*NS*	.75, $p < .01$
3. Action transactivity			*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
4. Own-collaborative				*NS*	.99, $p < .01$	.44, $p = .02$	*NS*	.40, $p = .03$
5. Peer-collaborative					*NS*	.51, $p < .01$	.98, $p < .01$	.46, $p = .01$
6. Collaborative-own						.44, $p = .02$	*NS*	.40, $p = .03$
7. Peer-own							.49, $p < .01$	.96, $p < .01$

8. Collaborative-peer									.40, p = .03
9. Own-peer									

Discussion and conclusion

Results presented in this paper seem to indicate a beneficial effect of discussing identical information on both individual learning and equivalence between partners with respect to their level of outcome knowledge. In addition, the extent to which participants manipulate their partner's contribution in the collaborative concept map (action transactivity) tend to be higher when they share identical (rather than complementary) information. In other words, discussing identical information seems to lead participants to construct together the concept map in a more collaborative fashion. No evidence of any positive relation between transactivity at the action level and learning outcomes was however found. Thus, these results tend to support the hypothesis of the superiority of knowledge independence (Doise & Mugny, 1984). Based on Buchs et al.'s (2004) studies, three explanations of our results regarding the effects of knowledge (inter)dependence with the partner could be suggested. First, in our study, individual learning was tested only immediately after collaboration; it would be helpful to also measure delayed learning since it was found that the beneficial effect of discussing identical information on immediate performance does not persist with time (Buchs & Butera, 2001; Buchs et al., 2004). Second, the texts we built for this experiment can be perceived by (low prior knowledge) participants as being relatively complex; due to the text complexity, we could expect that the quality of explanations generated during interaction would be higher in the SI condition than in the CI condition. A verbal interaction analysis is thus required to deepen the effects of knowledge interdependence with the partner. Third, compared to Buchs et al.'s (2004) studies in which partners had only to explain to each other what they had understood about texts to which they were respectively assigned, in the CI condition of our study, there was interdependence with the partner with regards to both the knowledge level and the task level: participants could build neither a complete internal model of the learning topic (both electric and ionic information was needed to understand the functioning of the neuron) nor a good concept map individually. We may thus assume that it would be better for participants to share identical (rather than complementary) information when they are dependent on each other to complete the collaborative task.

Eye-tracking data provide interesting insights about how knowledge interdependence may influence the way participants distributed their eye-gaze among the three different visualizations (collaborative, own, and peer maps) during the course of interaction. First, we found that participants sharing complementary information (a) focused twice longer on their own individual map and also, (b) transitioned more frequently between their own map and the partner's map (and vice-versa) compared to those who shared identical information. Second, results showed a negative relation between the amount of time participants spent looking at their own map and learning outcomes. The number of own-peer (and peer-own) eye-gaze transitions was also negatively correlated with learning measures at both the individual and dyad levels. Finally, results do not give support for the hypothesis of a relation between the amount of time spent looking at the partner's individual map (visual transactivity) and collaborative learning. On the one hand, these findings seem to indicate a negative impact of providing students with the availability of their own individual map during collaboration. Based on eye-gaze data only, it is quite difficult to infer what type of cognitive activity participants engaged in when consulting their own map. One interpretation is that the possibility to refer – at any moment of the collaboration – to their own (external) representation of the learning topic could be detrimental to the decentration necessary for participants to benefit from collaboration. On the other hand, regarding the own-peer and peer-own eye-gaze transitions, they cannot be interpreted in the same way across the two learning conditions. We hypothesize that these types of eye-movement transitions would reflect (a) a *visual comparison* between two graphical representations of the same text in the SI condition, and (b) a *visual coordination* of two complementary external representations (one displaying the electric model of the neuron, one about the chemical model) in the CI condition. One assumption is that it takes time and effort for participants to visually compare/coordinate their own- and their partner's prior knowledge maps; this would explain the negative relation between the number of own-peer (peer-own) eye-gaze transitions and learning outcomes. Moreover, the higher number of own-peer (peer-own) eye-gaze transitions in the CI condition, suggests that participants who shared complementary information experienced more difficulties in coordinating their own map and their partner's map; this could be one interpretation of their lower learning performance. To sum up, our data do not support the hypothesis of a positive effect of making visible – through external representations – differences in prior knowledge between co-learners during the course of interaction (Engelmann & Tergan, 2007). Additional analyses are required to better explain the negative relation between learning outcomes and eye-gaze transitions between one's own- and the partner's prior knowledge maps. In particular, it would be helpful to investigate characteristics of verbal interaction patterns occurring during these eye-movement transitions.

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