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Are you with me or not? Temporal synchronicity and transactivity during CSCL

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Abstract Do the simultaneous alignment of student activities (temporal synchronicity) and students successively building on each other's reasoning (transactivity) predict the quality of collaborative learning products? To address this question, we used a mixed-method approach to study 74 first-year university students who were randomly assigned to work in dyads on an ill-defined problem of biodiversity collapse in tropical forests within a computer-supported collaborative learning setting. The quantitative analysis revealed that neither temporal synchronicity nor transactivity was related to the quality of group products. The qualitative analysis of chat transcripts revealed that the variability between the groups could be explained by group dynamics, students' prior knowledge, confidence in managing the learning task, collaborative strategy and communication skills. The study findings could be used to optimize collaboration by informing students directly of their activities or the teachers that scaffold these activities.

Keywords computer-supported collaborative learning, environmental education, quality of group products, temporal synchronicity, transactivity.

Introduction

Consider two students solving a problem together. While Student 1 adds a new argument to their shared workspace, Student 2 browses the course materials looking for the meaning of a concept he does not yet understand. Just when he thinks he found a relevant passage, the chat window blinks, indicating a new message arrived. Student 2 opens the chat window. 'What do you think of my argument? Does it make sense?' Student 1 asks. 'Yeah, I will add my opinion to it in a minute', Student 2 responds. He goes back to reading the learning material.

This situation illustrates an important aspect of collaboration: in order for collaborating students to succeed, students have to stay 'in tune' with each other's activities (Erkens, Jaspers, Prangsma, & Kanselaar, 2005). In the preceding example, the two students are out of sync on multiple levels. Temporally, it seems they follow different tracks of activity (one is working on adding arguments, and the other is catching up on conceptual understanding). From a communication perspective, no real discussion is taking place (one student starts the conversation, but no discussion ensues). These two process characteristics, namely, the question of whether collaborative activities are synchronized across time (*temporal synchronicity*) and the extent to which students build on each other's ideas (*transactivity*), might give students an idea of whether their collaborative partner is 'with them' or not. The focus of this paper is to examine to what extent temporal synchronicity and transactivity affect the quality of group products, for example, the products

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students collaborate on and which can be viewed as the externalization of their learning.

Theoretical framework

Since the 1990s, many studies have aimed at providing insight into the use of computer-supported collaborative learning (CSCL) as an instructional strategy (Stahl, Koschmann, & Suthers, 2006). In CSCL, two or more students jointly solve problems or build knowledge supported by specifically designed software (Prinsen, Volman, & Terwel, 2007). This kind of learning is characterized by the negotiation of meaning, collaborative sense making and thus the sharing and construction of knowledge among students working together (Dillenbourg, Järvelä, & Fischer, 2009). In their framework of collaborative knowledge construction, Weinberger and Fischer (2006) describe four dimensions to analyse process characteristics of collaborative learning, namely, *participation* (who is active), *epistemology* (what is being discussed), *argumentation* (how are arguments put forward) and *social modes* (how do students build on each other's contributions). Especially concerning this last dimension of social modes of collaboration, recent advances in the CSCL literature indicate that the effectiveness of collaborative learning is influenced by the extent to which students can ensure the consistency of the joint work product by temporally synchronizing their collaborative activities (Erkens et al., 2005), and by the extent to which students can identify and discuss conflicts in their knowledge and beliefs, that is, transact on each other's ideas (Kirschner, Beers, Boshuizen, & Gijselaers, 2008; Stahl, 2013). In other words, learners are required to attune to each other both at a macro level (in terms of their collaborative activities like co-constructing a concept map or co-writing an essay) and at a micro level (verbal exchanges of content knowledge and beliefs), during discourse. Attunement at these two levels may ensure that collaboration is both efficient and effective.

While temporal synchronicity and transactivity have been studied separately, knowledge is lacking concerning the combination of these aspects into one model or the relation between them. To contribute to the knowledge base of collaborative learning processes, this study investigates the relation between temporal synchronicity, transactivity and the quality of collaborative learning products. These products can be any type of physical or virtual artefact that the groups produce as a result of their collaborative activities: a report, an essay, a design, a concept map, a presentation and so on. These products can be viewed as the reflection of the current state of students' conceptual understanding of the content or of the mastery of a certain competence (Puntambekar, Erkens, & Hmelo-Silver, 2011). The quality of the produced collaborative products can be accurately and consistently evaluated with the help of various analytical approaches and assessment tools, for example, a scoring system, text analysis or discourse analysis, or written assessments.

In the next sections, the separate lines of research concerning coordination of activities (temporal synchronicity) and integration of discourse (transactivity) are discussed in more detail, as well as the scientific contribution and practical relevance of this paper.

Temporal synchronicity

Synchronizing collaborative activities across time and appropriate distributions of efforts and resources are of critical importance to a group's performance (Erkens et al., 2005; Mayordomo & Onrubia, 2015). Previous research on CSCL indicates that collaborative problem solving is considered as a sequenced process, usually incorporating joint and individual working phases across time (Barron, 2000; Ploetzner, Dillenbourg, Preier, & Traum, 1999). Each phase has specific objectives and requires specific types of activities or acts of transferring information from one participant to another [e.g., via written communication (chats and discussion boards) or visualizations (graphs, charts and maps)] during collaboration to be effective (Hmelo-Silver, Chernobilsky, & Jordan, 2008). We define temporal synchronicity as a state in which the activities of a collaborating group are synchronized across time, that is, when group members are working on the same activity at the same time (Baker, 2002). While coordination and regulation of collaborative processes are of critical importance to the overall performance of a group (Erkens et al., 2005; Rummel & Spada, 2005), only few studies have focused on temporal aspects of regulation of collaboration (with some notable exception, see Hmelo-Silver et al., 2008; Molenaar & Järvelä, 2014).

The type of CSCL environment in terms of synchronous or asynchronous forms of collaborating has distinct variations of temporal synchronicity and its measurement – ranging from being in the same working space at the same time to coordinated effort over time (e.g., 24-h knowledge factory well known in the field of computer-supported collaborative work). In this paper, we focus on synchronous collaboration.

Earlier research in CSCL shows that temporal synchronicity of collaborative activities entails agreeing on task-related strategies, arranging the division of tasks between the participants and achieving a shared task alignment and establishing chronological order of activities (Baker, 2002; Erkens et al., 2005). According to Baker (2002), 'the degree of alignment refers to the extent to which participants are "in phase" with respect to different aspects of the problem-solving activity, that is, to what extent they are genuinely working together' (cited from Arvaja, Häkkinen, & Kankaanranta, 2008, p. 268). Collaborative problem solving is non-aligned or non-synchronized when, for instance, one partner focuses on individual achievement over collective teamwork or there is no mutual agreement on a chronological order of activities.

Literature on the relation between temporal synchronicity and group performance is not univocal. On the one hand, failure to maintain continuous attention and reflection on one's own understanding as well that of fellow group members can lead to process losses (Baker, 2002; Schneider & Pea, 2013). Recent studies show that shared visual attention on the task positively predicts outcomes of collaboration (Schneider & Pea, 2013; Schneider et al., 2016). On the other hand, Rummel and Spada (2005) suggest that besides temporally synchronized activity, for collaboration to succeed, individual activity might be equally important. Their study revealed that 'successful dyads were mostly to be found in the quadrant with the higher amount of individual work, whereas unsuccessful dyads were predominantly situated in the quadrant with the lower amount of individual work' (Rummel & Spada, 2005, p. 231). Also, high-achieving dyads had relatively well-balanced proportion of individual and joint work compared to low-achieving dyads.

Thus, there seems to be a delicate balance between phases of individual work and phases in which members of a collaborating group are temporally synchronized and work on the same (sub)task. In this study, we will further examine the extent to which collaborating dyads synchronize their activities, and whether this is related to the quality of the output of collaboration.

Transactivity

Besides attunement in terms of temporally synchronizing activities, collaborating groups may also attune their communication by building on each other's ideas. Based on the Piagetian approach of socio-cognitive conflict, the efficacy of collaborative learning effort is thought to be influenced by the extent to which students can identify and discuss conflicts in their knowledge and beliefs (Barron, 2003; King, 1997). It is assumed that students working in groups adopt shared understanding and negotiate the meaning about a topic by asking questions, discussing, explaining and providing additional information to support their viewpoints (De Lisi & Golbeck, 1999). This type of group discussion is known as transactive discussion, that is, when students successively build on each other's reasoning by interpreting the meaning of their logical statements on the task at hand (Teasley, 1997). Previous research has shown that learning is particularly likely to occur when the collaborating students engage in transactive discourse (i.e., critique, challenging of positions and attainment of synthesis via discussion), because this form of discourse gives rise to cognitive activities that stimulate knowledge construction (Andriessen, Baker, & Suthers, 2003; Cho & Jonassen, 2002). For example, when students challenge each other's ideas, they are forced to formulate arguments or evidence for their claims.

Berkowitz and Gibbs (1979, 1983) were the first to operationalize the construct of transactivity and introduced 18 types of transactive statements (e.g., critique: 'Your reasoning lacks an important distinction, or raises a questionable conclusion'; and integration: 'We can combine our positions into a common view'). In addition, transactive statements can be self-oriented (operates on the student's own reasoning) or other-oriented (operates on previously stated reasoning of a collaborative partner) (Berkowitz & Gibbs, 1979; Teasley, 1997).

In a study conducted by Teasley (1997), students collaborated on Schauble's (1990) race car task. The students needed to predict the speed of a race car before the car went on the racetrack. The study results showed that students who engaged in transactive discussion were more successful at predicting correct answers than the students who did not have this kind of transactive interaction. In another Teasley (1995) study, fourth-grade students were asked to solve a computer-based scientific reasoning task. Analysis of students' verbal interactions revealed that those dyads of students who used one another as information resources and built on each other's reasoning generated better hypotheses and had more interpretive types of interactions compared to students who worked alone.

Research on CSCL shows that 'learners typically do not engage in "high-level" collaboration processes without guidance' or scaffolding (Fischer, Kollar, Stegmann, & Wecker, 2013, p. 57; Noroozi, Weinberger, Biemans, Mulder, & Chizari, 2012). For the fostering of students to engage in transactive interaction, various technology-enhanced and teacher-enhanced scaffolding techniques (e.g., collaboration scripts, sentence openers or prompts) have been used to offer guidance and trigger the construction of specific arguments, externalization of students' own knowledge and elicitation of their collaborating partner's knowledge (Kollar, Fischer, & Hesse, 2006; Weinberger, 2011; Weinberger, Stegmann, & Fischer, 2007).

Similarly, Noroozi, Weinberger, Biemans, Mulder, and Chizari (2013a) discuss how transactive discourse might result in increased individual learning gains. Externalizing information to the learning partner and eliciting information from the learning partner result in the transfer of theoretical concepts from individual to dyad, and vice versa. Several other studies have also linked a greater student engagement in transactive forms of discussion with increases in both individual and group learning outcomes (e.g., Ai, Sionti, Wang, & Rosé, 2010; Noroozi, Biemans, Weinberger, Mulder, & Chizari, 2013b).

The way collaborating students build on each other's contributions can be carried out at varying levels of transactivity (Arvaja et al., 2008; Berkowitz & Gibbs, 1979; Mercer, 1996; Noroozi et al., 2013a). At the lowest level, simple consensus occurs when group members accept what is said or done without further discussion. At the highest level of transactivity, a joint decision is made as a result of a dynamic incorporation of both agreements and disagreements between partners (Molinari, Sangin, Dillenbourg, & Nüssli, 2009). Both levels of transactivity have been shown to be conducive to learning but to imply different levels of engagement in the collaboration process. Previous research has shown that it is especially the highest form of transactive discourse that increases the probability that learners trigger cognitive activity fostering individual and group performance (Stahl, 2013).

The present study

Temporal synchronicity and transactivity reflect two types of attunement, namely, at the temporal and communicational levels. While the importance of temporal synchronicity and transactivity have been separately shown, few researchers have combined these aspects into one model or studied the relation between them. Gómez et al. (2013) suggest that joint attention to the task mediated by a computer increases the tendency to build knowledge transactively. Seen this way, it might be hypothesized that coordination on a macro level, that is, temporal synchronicity, is a prerequisite for coordination on a micro level, that is, transactive discourse. The study by Gómez et al. was conducted with young children between the ages 5 and 6 years; therefore, the question is whether similar findings can be confirmed for learners in higher education, which is the setting of the present study.

Based on previous research in the separate domains of temporal synchronicity and transactivity, it could be hypothesized that these two types of attunement indeed influence each other. For example, when students are temporally synchronized, it could mean they spend more time discussing the task and thus that there is more opportunity for transactivity to occur. On the other hand, the evidence that lapses of individual activity are important (Rummel & Spada, 2005) implies that lower degrees of temporal synchronicity (and possibly, less occurrence of transactivity) could also be beneficial for the quality of group products. The present study therefore aimed to build on previous literature by investigating the relation between temporal synchronicity, transactivity and the quality of collaborative learning products in the context of synchronous CSCL.[1]

Besides the scientific relevance of gaining insight into process characteristics of collaboration and their relation to outcomes (Molenaar & Järvelä, 2014), the study also has practical relevance. By examining which process characteristics positively influence quality of group products, it is possible to inform instructional design choices and to help teachers encourage specific types of student activities to improve the quality of collaboration in terms of process and output.

The following research question was addressed:

> What is the relation between temporal synchronization of collaborative activities, the use of high levels of transactive discourse, and the quality of group products during synchronous CSCL?

The research question was approached using both quantitative analyses and a qualitative exploration to enhance and explain the statistical analyses.

Method

Participants

The participants in this study were 74 first-year graduate students enrolled in an Environmental Sciences master programme in the Netherlands. The sample comprised of 18 Dutch and 56 international students; 53% were women. Of the international students, 18 came from Europe, 6 from Africa, 25 from Asia, 6 from South America and 1 from North America. The total number of countries represented in the study was 22. All of the participants had demonstrated English language proficiency when enrolling at the university where this research was conducted. The age of the respondents ranged from 19 to 37 years, with a mean age of 24 years ($SD = 3.2$); 96% of the participants were under the age of 30.

Participants had diverse cultural backgrounds. For collaboration conditions to be similar for all study participants, all dyads were culturally heterogeneously composed, meaning they consisted of two students with differing cultural backgrounds. Within the different cultural types, participants were randomly assigned to a partner from a differing cultural background. The resulting dyad composition in terms of gender was either male ($n = 9$), female ($n = 11$) or male–female ($n = 17$).

One dyad was excluded from data analyses as they did not use the CSCL environment for communication but used face-to-face communication.

Learning materials and assignment

This study used an assignment that was part of an introductory course for master students called Principles of Environmental Sciences. To fulfil this assignment, students had to analyse the problem of biodiversity collapse in tropical forests. While collaborating in dyads within a synchronous CSCL environment, students were expected to inductively solve an environmental problem, by following three consecutive steps: (1) analysing the problem of biodiversity loss by identifying causes and effects, (2) proposing possible responses (solutions) to avert the biodiversity loss and (3) selecting the most viable ways to tackle the problem of biodiversity loss by prioritizing the responses. Students were expected to fill in a driving force–pressure–state–impact–response (DPSIR) model for an ill-defined environmental problem to which several solutions could be proposed (i.e., DPSIR is a framework that helps to identify and describe processes and interactions in human–environmental systems, Fortuin, van Koppen, & Leemans, 2011). The goal of the collaborating task was for students to gain knowledge about the human–environmental system, that is, to gain conceptual knowledge. In the context of the present study and for this specific learning task (DPSIR), it was critical to reveal the extent to which students can identify and describe processes and interactions in human–environmental systems from a conceptual perspective. Concept mapping is a good means of assessing the relationships that collaborating students perceive among the concepts (İngeç, 2009; Ruiz-Primo, 2004). Therefore, the CSCL platform included a tool for concept mapping (the Diagrammer).

Prior to the start of the study, a questionnaire was administered to collect general demographic information on the participants' and their prior knowledge of the DPSIR framework. None of the participants had prior knowledge of the DPSIR framework.

CSCL platform

The dyads collaborated in a digital learning environment called Virtual Collaborative Research Institute (VCRI; Jaspers, Broeken, & Erkens, 2004). Each student was seated at a different computer. The VCRI groupware program incorporated both personal tools (Sources tool and Notes tool) that were only accessible to the specific student, as well as shared tools (Chat tool, Cowriter tool and Diagrammer tool) in which activity from one of the group members was immediately visible to the other. Figure 1 shows a screenshot of the VCRI environment. The Sources tool included a description of the assignment and the background materials needed to solve the task. The Notes tool is a personal space to write down notes. The Chat tool allowed students to communicate with their collaborative partner. The Cowriter tool is a shared text editor, in which students wrote their responses and

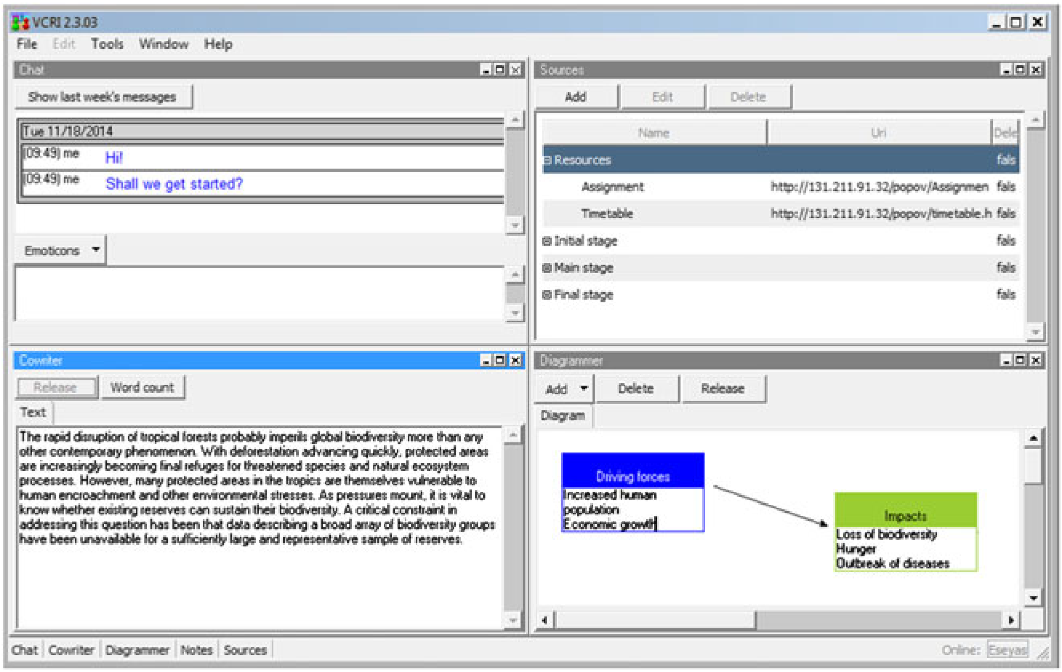

Figure 1 Screenshot of the Virtual Collaborative Research Institute (VCRI) environment, with the Chat tool (upper left), Sources tool (upper right), Cowriter tool (bottom left) and Diagrammer tool (bottom right). [Colour figure can be viewed at wileyonlinelibrary.com]

the prioritization of those responses. In the Diagrammer tool, students could build a DPSIR model by adding boxes and arrows that represent the elements of a DPSIR model and the relations between the elements.

All online activity was automatically captured in log files, which were further analysed for temporal synchronicity and transactivity.

Instruments

Temporal synchronicity

Log files were automatically generated for each dyad's activities in VCRI, including which tools were opened and what actions were performed within the tools. It was quantified whether the two members of a dyad mirrored each other's activity by opening and working in the same tool at the same time. An automatic coding mechanism, using Multi Episode Protocol Analysis (Erkens, 2005), was developed, which coded at each time point whether or not the two members of the dyad were temporally synchronized, and if so, in which tool. Without the availability of guidelines from previous work on quantifying temporal synchronization, we had to make a decision for a threshold of shared activity to count as temporal synchronization. We decided on a threshold of at least five consecutive activities for this variable to be a meaningful measure; this threshold means that longer periods of shared activity also count but excludes coincidental or random shared activity, which could be the case when two or three activities occur in the same workspace or tool. Therefore, the following two conditions had to be met in order for a dyad to be coded as temporally synchronized:

1. The dyad performed at least five consecutive actions within one specific tool, with the inclusion of Chat messages. Because the Chat tool was the primary medium for communication, the consecutive actions in a tool still count if an action in the Chat tool occurs within this row of five activities.
2. The row of (at least five) consecutive activities includes activities produced by both members of the dyad. For example, five activities by member 1 in the Diagrammer do not count as the dyad being temporally synchronized.

Thus, when a sequence of activities met the criteria, all activities in those sequences were coded as temporally synchronized (Table 1). The percentage of the total

Table 1. Examples of Coding Temporal Synchronicity

Line	Activity student 1	Activity student 2	Coded as
1	Cowriter opened	Cowriter – editing text	Dyad temporally synchronized in Cowriter
2	Cowriter opened	Cowriter – editing text	
3	Cowriter opened	Cowriter – release text	
4	Cowriter – claimed text	Cowriter opened	
5	Cowriter – text edit	Cowriter opened	
6	Cowriter opened	Sends Chat message	
7	Sends Chat message	Chat opened	
8	Sources – screen opened	Chat opened	Dyad no longer temporally synchronized
9	Sources – open a source	Chat opened	
10	Sources opened	Chat message	
11	Sources opened	Cowriter focus	

At lines 1–7, the dyad is temporally synchronized in the Cowriter. At line 8, temporal synchronicity ends because student 1 opens the Sources tool.

number of activities that was coded temporally synchronized was used as the measure of temporal synchronicity for each dyad.

Transactivity

The effectiveness of collaboration was assessed by the quality of the DPSIR model in the Diagrammer. Thus, the artefact the groups worked on (the Diagrammer) was seen as the externalization of learning that occurred during collaboration. To make sure the measure of transactivity (the independent variables) was in line with the measure of learning (the dependent variable), we investigated to what extent the content of the Diagrammer was discussed by the dyads on a high level of transactivity. This decision was also made because the number of chat utterances as well as the amount of off-task chat utterances varied considerably between groups. Therefore, measuring transactivity purely based on the chat discussion would have been an unfair comparison between groups. Thus, for each dyad, it was examined what percentage of the elements in the Diagrammer originated from transactive discussion.

Each DPSIR model consisted of several concepts (e.g., ‘Deforestation’) that were grouped into bigger categories (e.g., ‘State’); see earlier explanation. For each dyad, the concepts within the DPSIR model were listed.

Then, for each dyad, the entire chat discussion (which was automatically saved by VCRI) was coded for occurrence of high-level transactivity. This was carried out using the operationalization of Integration from Noroozi’s hierarchy of transactivity (Noroozi et al., 2013b), which means that learners adopt the perspective of their peers and build syntheses of the (counter) arguments uttered by their peers. For an example of high-level transactivity, see Table 2. A randomly selected third of all chats were coded by the three researchers, and the outcomes were discussed until consensus about the coding was reached. Afterwards, coding of the remainder of the discussions was divided between the researchers. In chat episodes where disagreement about the correctness of coding as high level of transactivity in the integration category occurred, consensus was reached through discussion by all three researchers.

When all discussions were coded, the lists of concepts from the Diagrammer were compared to the coded excerpts. For each concept, it was coded whether it was discussed on a high level of transactivity within the chat. This was checked by two researchers.

Finally, the percentage of concepts from the Diagrammer that was discussed on a high level of transactivity was used as a measure of transactivity.

Quality of students’ group work

Because the task concerned an ill-defined problem, there was not one unique correct DPSIR diagram. The assessment of the quality of the students’ constructed DPSIR diagrams (obtained from the Diagrammer tool) was made on a 5-point rating scale (5 being the best score) for three assessment criteria: *width* (the number of concepts in the Diagrammer), *correctness* (the amount of concepts that is correct, i.e., relevant to the topic and positioned in the appropriate diagram box) and *structure* (the way concepts are grouped and related within the Diagrammer). See Figure 2 for an example of a diagram in the Diagrammer tool.

Table 2. An example of transactive discourse

Student	Utterance
Student 1	so we both mention land protection
Student 2	yeah \
Student 1	but you go further to discuss CO2 capture
	a good point
	i didn't mention green house gasses, but a notable point
Student 2	so lets [let's] merge them and come up with a good one \
Student 1	sounds good.
Student 2	so bring the Responses table lets [let's] start
Student 1	lets [let's] add the wild dog/biodiv [biodiversity]/to my first point
Student 2	so u [you] can write that down as we talk
	*chat
Student 1	yeah
Student 2	so planting trees will partially solve the green house effect
Student 1	theoretically.... yes
	but so many would be needed
Student 2	it is a start though…
Student 1	we can pull something from this
Student 2	Yeah
	go for other electric sources instead of daming [damming] big rivers
	or do it in an environmentally friendly way ....like allowing the sediment flow some how
Student 1	yeah
	how's that looking to you?

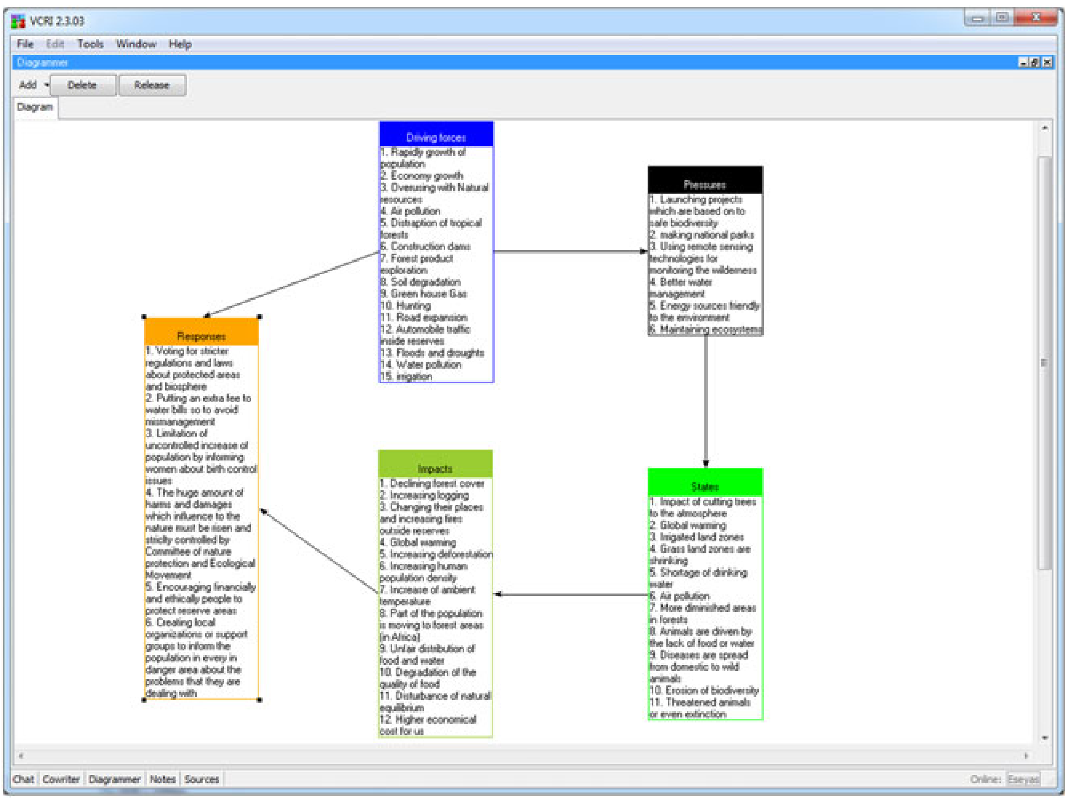

Figure 2 Example of a diagram in the Diagrammer tool. [Colour figure can be viewed at wileyonlinelibrary.com]

Two teachers coded the quality of the diagrams. They first discussed a prototype of a correct solution. They then coded all students' DPSIR diagrams independently. Disagreement and discrepancies were discussed until agreement was reached. Both inter-rater agreement between the teachers (Cohen's k = 0.82) (Landis & Koch, 1977) and intra-coder test–retest reliability for each teacher for 15% of the data (90% identical scores) were sufficiently high.

Subsequently, all points assigned to each student dyad per criterion were added together and then divided by 3 (i.e., the total number of criteria). Each group of students could get a mean quality score of between 1 and 5, which was converted to the Dutch 10-point grading scale (with 10 being the highest score possible). Scores below 5.5 were insufficient to pass the course.

Procedure

In the study, one introductory (plenary) (duration 1.5 h) and two online group work sessions (duration 7 h) occurred over 3 days. The overall time required for completion of the assignment was about 8.5 h. All dyads participated in all sessions and thus followed the same structure of activities. In the plenary meeting, the DPSIR model was introduced. In the first group working session on day 2, students were seated at individual computers. The two members of a dyad were assigned to different classrooms and only used the Chat tool within VCRI to communicate. The session started by spending a few minutes getting to know each other and continued by studying the task materials individually. Students were then given time to post their individual thoughts, and to exchange ideas with their peers afterwards. On day 3, students continued working on the collaborative problem-solving task and a solution evaluation phase took place. This phase consisted of three subtasks, namely, constructing a DPSIR model, making a list of possible responses and reporting the overall prioritization of the responses. The assignment ended in a finished DPSIR model, which was assessed by the teachers.

One teacher and one researcher were available for problem shooting with the assignment or the CSCL environment, but dyads were encouraged to finish the assignment by themselves. Both the teacher and researcher ensured that dyads only used the VCRI environment to collaborate, answered students' clarifying questions regarding the assignment and procedure and kept track of the time allocated for the task completion.

Analyses

A multiple regression analysis was performed to investigate whether temporal synchronicity and the percentage of concepts discussed at a high level of transactivity predicted the grade that the dyads received for their Diagrammer final product. Thus, in terms of Weinberger and Fischer's (2006) framework of collaborative knowledge construction, these quantitative analyses investigate the dimension of *social modes* of collaboration, because they concern to what extent group members' behaviour is attuned to each other.

The quantitative results were extended by adding qualitative descriptions of the dyads' collaborative processes. In this additional qualitative analysis, we focused on the other three dimensions included in the Weinberger and Fischer (2006) framework, namely, participation (which group members are active), epistemology (what is being discussed) and argumentation (how are arguments put forward).

For the qualitative analysis, all dyads were first categorized based on the degree of temporal synchronicity and high-level transactivity. No guidelines are available for what constitutes a desirable level of temporal synchronicity (see Introduction section). The only hypothesis we could formulate is based on the work by Rummel and Spada (2005), who stated that 50% joint work and 50% individual work is ideal. Therefore, we created two categories: dyads that were temporally synchronized 50% of the time, plus or minus 17%, and dyads with other scores (between 0% and 33% and between 66% and 100%). In the second category, only dyads with low temporal synchronicity could be found (Table 3). The two resulting categorizations were therefore a desired versus undesired level of temporal synchronicity (Table 4).

Table 3. Descriptive statistics for main variables

Variable	*M*	*SD*	Min	Max
Temporal synchronicity (%)	40.8	8.7	25.0	62.3
Number of concepts discussed transactively (%)	39.5	23.1	0.0	85.7
Grade (out of 10)	6.4	1.0	3.8	8.4

Table 4. Summary of types of dyads, sorted according to temporal synchronicity, transactivity and grade (n = number of dyads)

		Low number of concepts discussed with high-level transactivity (0%–33.3%)	Medium or high number of concepts discussed with high-level transactivity (>33.3% concepts)
Undesired level of synchronicity 0.0%–33.3% or 66.7%–100%	Grade < 5.5 Insufficient	A $n = 0$	B $n = 1$ SUMMARY: This particular dyad collaborated but was not critical of each other's work. They regularly wanted to show their work to the teacher, possibly because they were insecure.
	Grade > 5.5 Sufficient	C $n = 5$ SUMMARY: The dyads all divide the tasks between them, leading to cooperation instead of collaboration, and little temporal synchronization.	D $n = 3$ SUMMARY: The dyads all divide the tasks between them, leading to cooperation instead of collaboration, and no temporal synchronization. The dyads have some moments where their activities intersect and at those points they discuss the task material on high-level transactivity.
Desired level of synchronicity 33.4%–66.6%	Grade < 5.5 Insufficient	E $n = 2$ SUMMARY: The dyads have a lack of high-level transactivity, in one case because the dyads divide the tasks and cooperate and in the second case because the students are too insecure to move beyond merely exchanging information.	F $n = 2$ SUMMARY: The dyads showed collaboration, including high-level transactivity in discourse, and often challenged each other. The low grade may be explained in one case because the dyad based their discussion on incorrect information and in the other case because the dyad spent too much time on figuring out the DPSIR model they had to construct.
	Grade > 5.5 Sufficient	G $n = 10$ SUMMARY: The dyads collaborated efficiently but showed no high levels of transactivity. There was a lack of challenging each other, instead quickly agreeing when the other proposed a solution. The students were determined to complete the assignment.	H $n = 13$ SUMMARY: The dyads collaborated efficiently and with regular occurrence of high-level transactivity. Ideas are constantly challenged in a friendly way, and the students regularly check whether they are still on the same page. Input from both students is combined into a co-constructed solution. The students are task oriented.

For transactivity, as described in the introduction, previous studies indicate that occurrence of high-level transactivity improves learning outcomes. Therefore, we created three categories: dyads where a low number of concepts in the Diagrammer was discussed with high-level transactivity (0%–33.3%), dyads with a medium number of concepts discussed with high-level transactivity (33.4%–66.6%) and dyads with a high number of concepts discussed with high-level transactivity (66.7%–100%). The distribution among these categories was 17, 14 and 5 dyads, respectively. Because of the few dyads in the last category, in the qualitative descriptions of the dyads, a distinction is made between low number of concepts and medium–high number of concepts discussed transactively.

A third dimension was added to categorize the dyads, namely, whether the grade for the Diagram was sufficient (above or below 5.5), leading to a total of eight types of dyads.

Then, the collaboration of all dyads within each of these eight cells was thematically analysed according to the three dimensions participation, epistemology and argumentation (Weinberger & Fischer, 2006) by examining the chat conversation as well as the ordering of events within the log files. To analyse the chat conversations, an open coding approach was used to identify meaningful events such as the occurrence of disagreement between group members or reaching a shared solution to a question (Barron, 2003; Rummel & Spada, 2005). Each event consisted of an episode in which each student had more than one chat utterance. With an iterative, bottom-up approach, all chat transcripts were analysed, from which the following themes emerged: group dynamics, students' content knowledge, confidence in managing the learning task, collaborative strategy (cooperation versus collaboration) and communication. Then, based on the emerged themes, the three researchers wrote brief summaries of the way students collaborated. When there was doubt about the accuracy of a summary, a second researcher analysed that dyad. From the summaries of all types of dyads, a characterization for each type of dyad was composed (Table 4).

Results

Relation between high-level transactivity, temporal synchronicity and quality of group product

Table 3 displays the descriptive statistics for the percentage of activities that were temporally synchronized, the number of concepts in the Diagrammer that were discussed on a high level of transactivity and the final grade for the Diagrammer. As can be seen, on average, the dyads achieved a relatively high level of temporal synchronicity, meaning that almost half of the time, collaborating partners were using the same tools at the same time, including direct communication through the chat. On average, almost 40% of the concepts in the final Diagrammer product were discussed on a high level of transactivity. The average grade was 6.42, and out of 36 dyads, only five dyads did not achieve a sufficient grade.

Analysis showed there was a very small, non-significant correlation between temporal synchronicity and number of concepts in Diagrammer discussed on a high level of transactivity ($r = 0.05$, $p = 0.68$).

Multiple regression analysis showed that neither temporal synchronicity [$\beta = -0.078$, $t(35) = -0.451$, $p = 0.655$] nor high-level transactivity [$\beta = 0.031$, $t(35) = 0.177$, $p = 0.861$] was a significant predictor of the grade that the dyads received for their Diagrammer final product. The small β values show these variables explained little variance in grade.

Qualitative description of dyads

No significant relationship between grades, high-level transactivity and temporal synchronicity was found. In fact, both relatively low and high scores on these dimensions led to sufficient grades in this study. To further explore these findings, we provide qualitative descriptions of collaboration types that occurred in the dyads in Table 4. These qualitative descriptions shed some light on the variability in outcomes between dyads. It also shows contrasts between groups with different characteristics and similar outcomes in grade, as well as groups with similar characteristics but different outcomes in grade.

A categorization of dyads was made based on three dimensions: synchronicity (desired versus undesired), number of concepts discussed with high-level transactivity (low versus medium–high) and grade (insufficient versus sufficient), leading to eight categories (see section for more explanation). Table 4 displays the distribution of dyads among these categories. As can be seen, one type of dyad did not exist in our dataset, namely, the combination of undesirable level of synchronicity, low number of concepts discussed with high-level transactivity and an insufficient grade (cell A).

In the following sections, we illustrate and contrast the types of dyads that showed similar process characteristics yet differed in the grade they received. For example, dyad types A and C both show undesired levels of temporal synchronicity and a low number of concepts discussed on high-level transactivity, yet type A achieves an insufficient grade and type C a sufficient grade. In these discussions, we use the themes that emerged from the qualitative analysis (see Method section): group dynamics, students' content knowledge, confidence in managing the learning task, collaborative strategy (cooperation versus collaboration) and communication.

Dyad types A and C

Contrary to our expectations, all dyads with lack of temporal synchronicity and a low number of concepts discussed on high-level transactivity fell into dyad type C (sufficient grade) in our study. Further analyses of dyad type C revealed that in some cases the dyads consisted of two strong students that could manage their own tasks by distributing the workload and coordinating their actions, instead of trying to collaborate and learn from each other. In other cases, one of the students in the dyad took almost full control of the task. As an example, we consider one dyad from type C (Table 5a), where one student is responsible for most activity in the Diagrammer tool and as a group, only 8.3% of concepts in the Diagrammer is discussed with high-level transactivity. Still, in contrast to dyad type A, this dyad achieved a high grade (8.4 out of 10 points). Student 1 takes control of the assignment, as evidenced by the use of the phrase 'my diagram'. As a result of this disproportional cooperation dynamic, the dyad discusses a low number of concepts with high-level transactivity and achieves a relatively low percentage of temporal synchronicity (29.1%).

Dyad types B and D

Dyad type B occurred only once in our dataset, whereas dyad type D had three instances. Both types of dyads, B and D, demonstrated a similar style of working together, namely, they discussed most matters in an open and constructive way. These dyads discussed their plans and activities verbally, agreed on what needed to be done and then proceeded individually, without temporal coordination. Qualitative analysis of chat transcripts revealed that dyad type B had to ask the teacher for help over ten times, partly because they thought they had to and partly because they felt insecure about what they had produced (Table 5b, left). In contrast, dyad type D managed their collaborative work without the teacher's help, and all content-related questions were discussed between the participants themselves (Table 5b, right).

Dyad types E and G

From the dyads that achieved a high level of temporal synchronicity in their collaboration and discussed a low percentage of their concepts at high-level transactivity, two dyads scored an insufficient grade (dyad type E) and ten dyads scored a sufficient grade (dyad type G). Overall, the dynamic of these two types of dyads was set on completing the DPSIR assignment, but not on learning from each other and understanding more about the subject matter. In situations when one student would pose a question or a suggestion, the other student would usually respond very briefly or agree very easily. The difference in grades may be explained by the dynamics of collaboration that these two types of dyads demonstrated. Students in both types of dyads collaborated very closely with each other in terms of tool use, but dyads in type E spent more time figuring out the assignment and doubting actions (i.e., one dyad in type E used the word 'Maybe' 42 times throughout their entire chat conversation) compared to dyads in type G. This is shown in the excerpts in Table 5c.

Dyad types F and H

From the dyads with both a desirable level of temporal synchronicity and a medium–high number of concepts discussed transactively, only two dyads scored an insufficient grade (type F), and 13 dyads scored a sufficient grade (type H). This supports our expectation that high-level transactivity and temporal synchronicity may lead to higher quality of group work. Further analyses of dyad type F shows that both dyad types are very polite, constructive and friendly in their chat. However, one of these two dyads had a low score (2 out of 5) on the correctness criterion, possibly indicating that they based the concepts in their Diagrammer on misconceptions. The other dyad spent much time figuring out what the assignment was about and what the idea behind a DPSIR model was. These difficulties in understanding the assignment seemed to be increased by language barriers between the two students in the dyad.

Twelve of the 13 dyads in dyad type H are characterized by challenging each other in a friendly and motivating way, showing patience and checking each other's ideas to come to co-constructed refined solutions (Table 5d). One dyad, however, started working on the Diagrammer very early on in the assignment but then had an argument the students themselves called a 'serious situation'. When the students realized the argument lasted for too long and they had to hurry to complete the assignment, they stopped arguing in the chat and were able to finish the assignment.

To summarize, the qualitative descriptions showed the variability between the groups in terms of group

Table 5. Excerpts from Chat discussions from dyad types

	Dyad type							
	Type A	Type B	Type C	Type D	Type E	Type F	Type G	Type H
Excerpts	—	Student 1: so the Diagrammer doesn't need to be modified .every item of response should be more specific	Student 1: Wow, you have finished the whole assignment.	Student 1: I will put my Notes on the Cowriter then you can see it. Is that OK?	Student 1: but the problem is that I don't know if we have to focus on the case described in the article or if we can find another impacts that are not in the text	Student 1: O I didnt understand that	Student 1: whil [while] you work i will summarize for you the other papers.	Student 1: Ah it belongs to air pollution
		Student 2: i don't know	Student 2: I already made something but don't know if its correct	Student 2: perfect!	Student 1: but I think you are right actually	Student 1: I thought we had to priorotize [prioritize] on which project is more important	Student 2: yes, i'm writting [writing] down what i get [got]	Student 1: or climate change
		Student 2: maybe we could ask to a teacher isn't it?	Student 2: Do we need to put all driving forces, for instance, in 1 box or in separate boxes?	Student 1: I still think the air and water pollution should be State	Student 1: and you speak about 50% forest loss but maybe we should put that in the pressues [pressures], as an explanation and proof of deforestation	Student 1: Sorry	…	Student 2: true, but emissions is a pressure and it pollutes the air. Shall I add it to the pressures?
		Student 2: did you saw what I posted about the 2 last points/	Student 1: I'm thinking about it now … I think we should ask someone else or the teacher	Student 2: I was just looking at your overview and I think you could be right	Student 2: maybe you are right	Student 1: Because then what you said makes total sence\ [sense]	Student 2: hmm, I have a question, does impact include negative ones?	Student 2: and air pollutions keeps standing there as a state
		Student 1: Yes	Student 2: You're messing up my diagram :P	…	Student 1: and the other ones, maybe we can develop a few by sentences from the text	Student 2: Yes, the one with most importance.	Student 1: impact is only including negative things, isn't it?	Student 1: yes! perfect!
		Student 1: and i post the 1	Student 1: I'm trying to find	Student 2: are you writing in the	Student 2: I don't know if we can find some impacts	Student 1: Important as in?	Student 2: yes, sorry i	

(Continues)

Table 5. (Continued)

Dyad type							
Type A	Type B	Type C	Type D	Type E	Type F	Type G	Type H
		out if I can add a box.	Cowriter part now? Because for some reason i cannot type or delete anything anymore	that are not in the text, too. so, maybe now we can just use the things given in the article or in the film		made a mistake, let's move on	
	Student 2: it seems to be good	Student 2: I can do it if you want	Student 1: no i m not		Student 1: which will be giving results faster?	…	
	Student 2: we should show the complete work to the teachers	Student 2: and you can chat me if you agree with what I add	Student 2: then you can do the adjustments now,		Student 1: Or which will give the most result?	Student 2: done	
			Student 2: :)		Student 2: That's the question.	Student 2: we can discuss it later	
			Student 1: I want to add overexploitation of resources such like oil		Student 1: Shall we ask a teacher?	Student 1: yes	
			Student 1: it was talked in the planet earth		…		
			Student 2: that's right: make it (over) exploitation because exploitation in general is also a pressure		Student 2: To be honest, I cannot read very fast, comparing to u Dutch people…		
			Student 1: OK		Student 1: Yeah off course		
			Student 1: can you see it?		Student 2: That's just my personal problem, cuz [because] I don't have problem with		

(*Continues*)

Table 5. (Continued)

Dyad type							
Type A	Type B	Type C	Type D	Type E	Type F	Type G	Type H
			Student 2: yes I see		listennig [listening] or writing. Student 1: yeah but like the letters are so different Student 1: Or do you learn latin letters in school? Student 2: Objectively, it's because of the letters.		

dynamics, students' content knowledge, confidence in managing the learning task, collaborative strategy (cooperation versus collaboration) and communication skills.

Discussion

With the use of both quantitative and qualitative analyses, this study investigated the relation between temporal synchronicity of student activities, transactivity of students' discourse and the quality of collaborative learning products.

First of all, the analysis showed no correlation between temporal synchronicity and number of concepts in the Diagrammer discussed transactively. As an explanation, it is possible that students were temporally synchronized in terms of tools other than the chat. Students may thus have been synchronized in terms of working on arguments but were not necessarily discussing these arguments transactively. Another possible explanation is that more temporal synchronicity does not automatically mean that students will engage more in transactivity. Our measure of temporal synchronicity indicated whether students were active in the chat at the same time, but interactivity in the Chat tool does not automatically equal high levels of social interaction (Kreijns, Kirschner, & Jochems, 2003). As later analyses showed, other factors were also of influence.

In contrast to expectations, neither temporal synchronicity nor the occurrence of high-level transactivity predicted the quality of group products. Sufficient grades were achieved when dyads showed little temporal synchronicity but discussed a high number of concepts transactively and vice versa, and even with low levels of both temporal synchronicity and transactivity. Earlier findings concerning the positive influence of temporal synchronicity and transactivity on outcomes of collaboration could therefore not be replicated (Hmelo-Silver et al., 2008; Noroozi et al., 2013b). Furthermore, no evidence was found for a favourable balance between individual and collaborative activities (Rummel & Spada, 2005); both dyads with a low and medium degree of temporal synchronicity could achieve a sufficient grade.

The qualitative analyses suggested that other variables that explain when and why collaboration leads to a sufficient final product are involved. The qualitative analysis of collaborating dyads showed that there were a number of variables, besides the two under direct investigation, that influenced whether a dyad would succeed or not. These factors were group dynamics, students' content knowledge, confidence in managing the learning task, collaborative strategy (cooperation versus collaboration) and communication skills.

Group dynamics, confidence and communication all contributed to a favourable atmosphere within the dyad that allowed the students to move forward on the task in a friendly and efficient way. Taking the time to create such an atmosphere is thus important, and while the task in this study already included some time for students to get to know each other, the duration of this activity may be extended and combined with specific question prompts during the conversation to start (informal) dialogue between students. Another option is to explicitly train students in collaborative skills or specifically in transactive discourse before working on the assignment (Jurkowski & Hänze, 2015).

Concerning collaborative strategies, it was found that by discussing their activities and agreeing on a clear task division, two students with strong content knowledge could work independently from each other and still achieve a good grade. These students were able to discuss efficiently and did not need to engage in elaborate, high-level transactive discourse. Possibly, given this specific task and these specific students' background, collaboration was not beneficial for these students (Kirschner, Paas, & Kirschner, 2009). Other situations in which partners were less 'equal' also occurred. Some of the processes that were observed in these dyads, such as the 'overruling' behaviour when a dominant student was coupled to an insecure student, show the importance of taking into account student background when composing dyads and when measuring transactivity.

The most surprising type of dyad we encountered was the type that scored an insufficient grade even though they had a desirable level of temporal synchronicity and discussed a medium or high number of concepts with high-level transactivity. A possible explanation emerging from the qualitative analysis was related to students' prior knowledge of the topic. It appeared that some students reasoned on false beliefs, meaning that their misconceptions about the task material remained undetected by the students themselves. This finding shows the importance of both social aspects and cognitive or task-related aspects of collaboration and is in line with findings from Barron (2003). Perfect socio-collaborative skills are only beneficial when students challenge each other's statements continuously and keep checking their output for correctness. Thus, besides feedback on their socially collaborative skills, students may equally benefit from feedback on the content of their discussion. This balance between support on the dimensions of social and cognitive aspects remains an important direction for research (Barron, 2003; Pijls, Dekker, & Van Hout-Wolters, 2007; Van Leeuwen, Janssen, Erkens, & Brekelmans, 2013; Popov, Biemans, Brinkman, Kuznetsov, & Mulder, 2013).

In summary, our findings indicate some suggestions for what type of support could be beneficial for the effectiveness of collaborative learning, namely, to spend considerable time to create a favourable atmosphere within groups, training students to engage in transactive discussion and to combine support focused on social and cognitive aspects of collaboration. Two common methods to implement CSCL support are by means of external representations that help students keep track of their discussion and the perspectives they are taking, as well as by means of scripts, which provide learners with guidelines or structures about how and in what temporal sequences to interact (Noroozi et al., 2012). A recent overview of the effectiveness of collaboration support indicates that CSCL scripts are particularly effective when they focus on stimulating transactive activities in combination with additional content-specific support (Vogel, Wecker, Kollar, & Fischer, 2016). The results of our study indeed confirm that supporting multiple dimensions of collaboration is necessary to increase the quality of group products as a result of collaboration. Thus, a multidimensional approach seems essential not only for analysing collaborative learning but also for supporting collaboration between students.

Limitations and directions for future research

This study was carried out in an authentic learning environment, but the study findings should be interpreted in light of some limitations. First of all, there were only a few dyads that discussed a high number of concepts with high-level transactivity. If variation in occurrence of high-level transactivity had been greater, we might have been able to more accurately measure the relation between transactivity and outcomes of collaboration. A possible explanation is that there was no interdependency (Salomon, 1992) between students within a dyad while working on the task (all students had the same materials). If students had for example been given differing task materials, they would have had to share and discuss, and high-level transactive discourse may have been more likely to occur. This also relates to our finding that some dyads distributed the activities between them instead of undertaking them collaboratively. Recent research (Deiglmayr & Schalk, 2015) indicates the most beneficial level of interdependency depends on students' prior knowledge, which underlines our finding of the importance of group composition.

Concerning temporal synchronicity, we checked whether both students had the same workspace activated, but not whether both students were actively contributing nor whether they actually acknowledged each other's presence. It could be argued that the two students explicitly needed to demonstrate awareness that 'they are attending to something in common' (Tomasello, 1995, p. 106), for example, by explicitly discussing task strategies. However, research on temporal synchronicity in the field of CSCL is relatively scarce. It is not yet clear to what extent implicit coordination such as temporal synchronicity differs or correlates to explicit types of coordination (in which students openly discuss coordination of activities), which is a much more common area of research (Järvelä & Hadwin, 2013). In this respect, we hope to have given input for future research.

Finally, it should be taken into account that this research was carried out in the context of *synchronous* CSCL. In an asynchronous setting, measures and findings concerning temporal synchronicity and transactivity may have been different. For example, in an asynchronous setting, students have more time to think of an elaborate rebuttal to a peer's argument, whereas synchronous settings require students to quickly react to their fellow students (Hrastinski, 2008). Furthermore, this research involved student dyads, and group size was thus relatively small. The number of students per group may have consequences for the process and outcomes of collaboration. For example, the risk of free riding is larger when group size increases (Simms & Nichols, 2014). In smaller groups, students have more time to interact and to ask each other critical questions, which could lead to more transactive discourse (Noroozi et al., 2012). Thus, it is important to keep the specific setting of this study in mind when interpreting the results.

Conclusion

Collaborative learning remains a multifaceted and complicated process, as demonstrated by the results of this study. By investigating both temporal and interactional aspects of computer-supported collaboration and utilizing quantitative and qualitative analyses, the aim was to gain insight into underlying processes of collaboration and their relation to group products. One of the conclusions that can be drawn from this study is that there is a challenge to understand and support collaborative learning by taking into account differences not only *between* but also *within* dyads.

Although the results showed no direct relation between temporal synchronization of collaborative activities, the use of high-level transactive discourse and the quality of group products during synchronous CSCL, this study can inform instructional design choices and suggests teachers could foster specific types of student activities to improve the quality of collaboration, and thereby the quality of group output. Our qualitative analyses indicated several social and cognitive aspects of collaboration where such support is most needed to benefit from CSCL.

Note

[1]Synchronous collaboration differs from asynchronous collaboration (Hrastinski, 2008). See the Discussion section for elaboration on this point.

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