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Exploring Regulatory Processes during a Computer-Supported Collaborative Learning Task Using Process Mining

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Published as:

Schoor, C., & Bannert, M. (2012). Exploring regulatory processes during a computer-supported collaborative learning task using process mining. *Computers in Human Behavior, 28*(4), 1321-1331. doi: 10.1016/j.chb.2012.02.016

Abstract

The purpose of this study was to explore sequences of social regulatory processes during a computer-supported collaborative learning task and their relationship to group performance. Analogous to self-regulation during individual learning, we conceptualized social regulation both as individual and as collaborative activities of analyzing, planning, monitoring and evaluating cognitive and motivational aspects during collaborative learning. We analyzed the data of 42 participants working together in dyads. They had 90 minutes to develop a common handout on a statistical topic while communicating only via chat and common editor. The log files of chat and editor were coded regarding activities of social regulation. Results show that participants in dyads with higher group performance (N=20) did not differ from participants with lower group performance (N=22) in the frequencies of regulatory activities. In an exploratory way, we used process mining to identify process patterns for high vs. low group performance dyads. The resulting models show clear parallels between high and low achieving dyads in a double loop of working on the task, monitoring, and coordinating. Moreover, there are no major differences in the process of high versus low achieving dyads. Both results are discussed with regard to theoretical and empirical issues. Furthermore, the method of process mining is discussed.

Keywords: computer-supported collaborative learning; social regulation; research methods; self-regulated learning; process mining.

Exploring Regulatory Processes during a Computer-Supported Collaborative Learning Task Using Process Mining

A collaboratively learning group has to regulate their behavior in a very similar way as a self-regulated learning individual: They have to analyze, plan, monitor and evaluate cognitive and motivational aspects during learning (Hadwin, Oshige, Gress, & Winne, 2010; Järvelä, Järvenoja, & Veermans, 2008; Volet & Mansfield, 2006). Whereas most research has concentrated on individual self-regulated learning and how it could be supported, e.g. by prompting measures (Bannert, 2006, 2009), so far little is known about social regulation of learning in groups.

In addition, the temporal order of collaborative learning activities has so far been widely neglected (Reimann, 2007). However, temporal information can play a crucial role in analyzing interaction during computer-supported collaborative learning (CSCL): When performed at the beginning of a discussion, some type of interaction can have a totally different influence on group learning than when it was performed at the end of the discussion (Kapur, Voiklis, & Kinzer, 2008). For example, Kapur et al. (2008) found that a high quality contribution at the beginning of a CSCL problem solving process did more good than those later during the discussion. Therefore, the temporal pattern within group interactions should be taken into account in further CSCL research.

In business research, there are methods to analyze process data in their temporal sequence (Agrawal, Gunopulos, & Leymann, 1998; Günther & Van der Aalst, 2007; van der Aalst, et al., 2003). This so called process mining includes both bottom-up and top-down methods. In this paper, we want to explore both social regulation in an exploratory way and the possibilities of process mining to contribute to our notion of temporal processes in social regulation. It is the aim of this study to further enhance our understanding of social regulation, thereby taking its temporal sequence into account.

In the remainder of this paper, we first give an insight into social regulation research showing that we so far know too little about social regulation during collaborative learning. Then, we present our own theoretical framework for analyzing social regulation. After that, we elaborate on the importance of the temporal sequence of learning behavior and on one specific method of process mining that can be used for analyzing the temporal sequence of learning behavior. We then explore social regulatory activities of dyads in a study on CSCL and apply the method of process mining in order to investigate the temporal patterns in these social regulatory activities.

1 Social regulation

The terms used for regulatory aspects in collaborative learning vary as do the concepts these terms refer to (Volet, Vauras, & Salonen, 2009). Researchers use “social regulation” (Volet, Vauras, et al., 2009), “co-regulation” (Hadwin, et al., 2010), “other-regulation” (Vauras, Iiskala, Kajamies, Kinnunen, & Lehtinen, 2003) or “socially-shared regulation” (Vauras, et al., 2003) for describing regulatory aspects in collaborative learning.

Social regulation as the broadest term refers generally to regulation in groups as opposed to self-regulated learning (Volet, Vauras, et al., 2009). Volet, Summers, and Thurman (2009) subsume under this term both other-regulation and socially-shared regulation. In this context, *other-regulation* refers to an unequal situation where one student takes a more active role in regulating the group process than the other(s) (Vauras, et al., 2003; Volet, Summers, et al., 2009). *Socially-shared regulation* on the other hand includes "constant monitoring and regulation of joint activity, which cannot be reduced to mere individual activity" (Vauras, et al., 2003, p. 35). This is close to Roschelle and Teasley's (1995) definition of collaboration as a coordinated activity resulting from continuously constructing and maintaining a joint problem space. The term *co-regulation* is sometimes used synonymously to social regulation (e.g. Volet, Summers, et al., 2009) but in a sociocultural context refers to a form of other-regulation (e.g. Hadwin, et al., 2010).

In her paper on metacognition in relation to self-regulation and co-regulation, Efklides (2008) includes in addition to a personal-awareness level and a nonconscious level a *social level of metacognition* in her model. It is this social level on which we assume social regulation to take place. During social regulation, not only individual metacognition occurs on the social level, but also the cognition of the group members' cognition (which could be named "group metacognition"). Thereby we follow the wording of Volet, Vauras et al. (2009) by using the term "social regulation" for all regulatory activities on the group level (other- and socially-shared regulation) in contrast to self-regulation.

In this line of research, the main concern is to identify events of socially-shared regulation and their benefits for learning (Lajoie, 2008). For example, Vauras et al. (2003) conducted an extensive case analysis of a dyad of high-achieving girls who collaboratively solved math problems. They found that the concepts of self-regulation and other-regulation were not enough to understand regulation in collaboration but that the notion of socially-shared regulation was needed as well. Iiskala, Vauras and Lehtinen (2004) continued this work with another case analysis and the development of an interaction flowchart to visualize metacognitive action. Iiskala, Vauras, Lehtinen and Salonen (2011) extended this research by relating events of socially-shared regulation to task difficulty and the process of problem solving. They found that events of socially-shared regulation occurred more often in difficult tasks and that their function was most often that of confirming operations followed by confirming or activating situation models. Volet, Summers et al. (2009) included in their theoretical framework not only the dichotomy of individual versus co-regulation within a group but also the dimension of low-level (acquiring knowledge) versus high level content processing (constructing meaning). They found that the occurrence of high level co-regulation differed across groups and meetings. Additionally, they found that "high-level co-regulation was most commonly preceded by a question or an explanatory statement" (Volet, Summers, et al., 2009, p. 140).

Other researchers (e.g. De Jong, Kollöffel, Van der Meijden, Staarman, & Janssen, 2005; Liu & Hmelo-Silver, 2010) start from self-regulated learning (SRL) and transfer the notion of different self-regulatory activities like orienting, planning etc. to social regulation. SRL comprises a complex interplay of cognitive, motivational, cognitive regulatory (metacognitive) and motivational regulatory components (Boekaerts, 1997). More successful learning seems to go hand in hand with more regulatory activities (e.g. Azevedo, Guthrie, & Seibert, 2004; Manlove, Lazonder, & De Jong, 2007; Moos & Azevedo, 2009). According to Bannert (2006), ideal cognitive regulatory activities during learning include orientation in order to get an overview over the task and resources, planning the course of action, evaluating the learning product and monitoring and controlling all activities. This notion is closely related to Winne's (1996) conception of self-regulated learning. De Jong et al. (2005)

also adopt a very similar conception of regulatory activities encompassing orienting, planning, monitoring, testing, restoring / directing, evaluating and reflecting. In their study on CSCL, they additionally included the category of grounding. They found this category to be the most frequent by far followed by monitoring and planning. However, De Jong et al. (2005) did not relate these social regulation activities to group performance. Liu and Hmelo-Silver (2010) analyzed the effects of two different hypermedia structures on co-regulated learning. They differentiated co-regulated learning into planning, monitoring and evaluation and found differences in the discourse of groups using different hypermedia structures. A very similar study is that of Manlove, Lazonder and De Jong (2007) who analyzed the differential effect of two software versions on the use of planning, monitoring and evaluation tools (within the software) by the learning groups. They also found differences between the groups regarding these activities. Järvelä, Järvenoja and Veermans (2008) concentrated on socially-shared motivation regulation and identified motivation regulation strategies in two groups during three tasks. Winters and Alexander (2011) conceptualized collaborative regulatory activities in terms of forethought, strategy (referring to performance), monitoring and motivation which they derived amongst others from Zimmerman's (2000) concept of self-regulated learning. They found positive relations of the collaborative regulatory process categories *strategy* and *monitoring* with performance.

All in all, research on the kind of regulatory activities performed in CSCL groups and their linkage to group performance is scarce (De Jong, et al., 2005). However, first results indicate that also in a group situation, regulatory activities are related with performance. In order to further explore this relationship, we developed a theoretical framework for analyzing social regulation on the basis of SRL conceptions and the concept of negotiation (see also Dillenbourg, Baker, Blaye, & O'Malley, 1996).

2 Theoretical framework

According to Efklides (2008, p. 283), monitoring at the social level "can take the form of reflection [and] leads to a ... negotiated representation of the person-in-context". Vauras et al. (2003) also associate social regulation with negotiation both at the task level and on a meta-communicative level. In our theoretical framework (figure 1), we take this idea of negotiation on. We assume that what we can observe of social regulation is a kind of negotiation (Dillenbourg, et al., 1996) and thereby building a common ground (Clark & Brennan, 1991) referring to regulatory aspects of the group task like orientation, planning, or evaluation. Figure 1 represents our notion of social regulation in the case of a two persons group. At the individual (self-regulatory) level, we follow Bannert (2006) by assuming apart from the processing of the task the metacognitive activities orientation, planning, and evaluation as well as monitoring and controlling of all these activities. On the group level, we expect to observe the negotiation of a joint understanding of orientation, planning, and evaluation as well as monitoring and controlling. This could be other-regulation but also true socially-shared regulation. On this level of analysis, we forgo the further distinction between these two kinds of social regulation. The processing of the task might be negotiated on the group level (true collaboration) but might also be executed on an only individual level and might in this case just be coordinated between the two group members. In this case, coordination is the controlling of task processing. Special attention has to be paid at monitoring and controlling on the group level. We assume that group level monitoring is informed by both individuals' monitoring of his own activities as well as of the joint negotiated understanding of group level activities. Controlling in contrast is also negotiated on the group level but influences group level negotiations not directly but indirectly via individual controlling processes of activities which in turn influence the negotiation on the group level.

Therefore, we should be able to observe at the group level the activities orientation, planning, task processing, evaluating, monitoring, and controlling in terms of coordination. However, we do not imply a temporal order in our theoretical framework. Nevertheless, the temporal sequence might be an issue that should not be neglected.

3 Temporal sequence of learning behavior

Most SRL models imply a time-ordered sequence of activities although there is no assumption of a strict order (Azevedo, 2009). Indeed, there is only scarce research on temporal matters in self-regulated learning. For example, De Jong (1994) analyzed sequences of self-regulatory activities of successful and less successful learners. He found differences in the kind and variability of executed sequences between learners. Additionally, sequences were different for different kinds of tasks. Hadwin, Nesbit, Jamieson-Noel, Code and Winne (2007) also analyzed sequences of self-regulatory activities in addition to frequencies and patterns. Their activity transition graphs show distinct differences in learning sequences between their 8 participants.

In addition, most research on CSCL neglects the temporal order of interaction activities during task completion (Reimann, 2007). However, as Suthers, Dwyer, Medina and Vatrapu (2010) point out, information about the sequence of events plays an important role in understanding interaction. Additionally, some type of interaction can have a totally different influence on group learning when performed at the beginning than at the end of interaction (Kapur, et al., 2008). In CSCL research, Perera, Kay, Koprinska, Yacef and Zaiane (2009) used sequential pattern mining in order to find activity sequences associated with better group performance. They used activities in a collaboration system (e.g. creating or modifying a wiki page) as units and could not find sequences that were clearly characteristic for better groups. However, they also argue that conventional summative statistics are not enough to capture those processes responsible for group differences.

4 Research aim

The aim of our study is to explore spontaneous social regulation during a CSCL task while taking the temporal order into account. Our research question is whether it is possible to identify patterns of social regulation which divide successful learning groups from less successful groups. In a first step, we want to identify social regulatory activities as described in our theoretical framework. Therein, we concentrate on the group level of the framework. In a second step, we want to explore possible temporal sequences which could distinguish successful from less successful groups. Therefore, we present in this paper the possibilities of process mining in order to discover sequential patterns. The method of process mining is described in the next paragraph. As Hadwin et al. (2007, p. 108) point it out: “Consistent with exploratory case study methodologies, findings are not intended to be generalized to a population, but rather to inform theory and analysis regarding”, in our case, social regulation.

5 Process Mining

Process mining has been developed in business context to serve three functions: "discovery of processes, conformance checking, and extension" (Frèrejean, 2008, p. 11). In CSCL research, we can use process mining in order to discover processes underlying chat logs. There are different methods with slightly different results. For the purpose of this paper, we used the Fuzzy Miner (Günther & Van der Aalst, 2007). This method is used to describe sequences found in event logs. Additionally, it is possible to abstract from too fuzzy information which occurs in very complex and unstructured processes. The basic concept behind it is the logic of a road map: More important routes are stressed while less important ones are abstracted from (Günther & Van der Aalst, 2007). In order to reach this goal, several steps are conducted:

1. Computation of fundamental metrics for events (so-called unary and binary significance and correlation)
2. Creation of a model containing all events and their relations
3. Simplification of the model by using conflict resolution, edge filtering, and aggregation and abstraction

5.1 Fundamental metrics of fuzzy mining

A process model consists of nodes (event classes) and edges (relations between two event classes). The Fuzzy Miner uses two concepts to decide about their occurrence in the resulting model: significance and correlation. In contrast to the notion of statistical significance and statistical correlation, significance "measures the relative importance" (Günther & Van der Aalst, 2007, p. 333) of either nodes or edges. Correlation on the other hand "measures how closely related two events following one another are" (Günther & Van der Aalst, 2007, p. 333) and exists therefore only for edges. From that result three fundamental metrics: unary significance (of nodes / event classes), binary significance (of edges / relations of two event classes) and binary correlation (of edges).

Unary significance results from aggregating frequency significance and routing significance of events. Frequency significance refers to the relative frequency of an event. The most frequent event gets the value 1, all other events a valued relative to their occurrence (between 0 and 1). Routing significance results from the difference between the number and significance of incoming and outgoing edges of a node. A node with a high difference between them is seen as more important for the process, because at this node the process either forks or merges, as are other nodes which might reflect e.g. regular saving of data. The weighting of both significance measures for the aggregated unary significance metric can be adjusted.

Binary significance results from aggregating frequency significance and distance significance of edges. Binary frequency significance results, in analogy to unary frequency significance, from the relative frequency of two events following each other with the most frequent sequence being assigned the value 1. In addition, not only immediately following events can be accounted for, but also long-term relations as there might be undesired events in between two desired events. The impact of long-term relations is usually attenuated by some function (e.g. linear, root). The distance significance refers to how much the edge significance differs from the source and target nodes' significances being of smaller value for higher difference. Thereby, crucial relations shall be amplified while weak relations are further weakened. The (weighted) aggregation of both frequency and distance significance forms the binary significance value.

Binary correlation is an aggregate of several correlation indices: proximity correlation, endpoint correlation, originator correlation, data type correlation, and data value correlation. Not all of them are meaningful in all contexts. Proximity correlation is computed from the time differences between two events: The shortest receives the value 1, a double time span receives 0.5 and so on. Endpoint correlation refers to the similarity of event names, while originator correlation refers to the similarity of originator names. Data type correlation and data value correlation refer to the similarity of event attribute types resp. their values.

The basic idea of the fuzzy miner is to simplify the complete model by preserving highly significant events or edges, aggregating less significant but highly correlated edges and nodes by clustering, and abstracting from less significant and lowly correlated edges and nodes by removing it from the simplified model (Günther & Van der Aalst, 2007). This simplification needs the following principles of conflict resolution, edge filtering, and aggregation and abstraction.

5.2 Conflict resolution

When two nodes are connected in both directions, they are believed to be in conflict (Günther & Van der Aalst, 2007). This might be due to three reasons: a real loop relationship, an exception for one observed direction, or two parallel processes one of them including event A and one of them including event B leading to the two events A and B following each other in both ways. Therefore the conflict is whether both edges should be preserved, one of them should be eliminated or in case of parallel processes both edges should be eliminated. To solve this conflict, a relative significance for both directions of the relationship of A and B is computed by relating it to other relationships of A respectively B (for the exact formula see Günther & Van der Aalst, 2007). If both relative significances are above a to be defined threshold (*preserve threshold*), a real loop is assumed. If one of them is below the threshold, the difference between both relative significances decides upon removal of edges: In case of a high difference value, only the edge with the lower relative significance is removed; in case of a low difference value, both edges are eliminated. In the former case, an exception is assumed, while in the latter case, parallel processes are assumed. What defines a high or low difference value, can be defined by setting the *ratio threshold*.

5.3 Edge filtering

In order to further simplify the model, the fuzzy miner reduces the number of edges by filtering them. There are two possibilities: preserving the two best (highest significant) edges per node or using the so-called utility of the edges. The utility is a weighted sum of significance and correlation of an edge. The *utility ratio* defines the weightings while with the *edge cutoff* the absolute threshold value for filtering edges is determined.

5.4 Aggregation and abstraction

The last mean to simplify the model is node aggregation and abstraction. A node *significance cutoff* is set which determines whether a node remains in the model or not. If the unary significance of a node is lower than the cutoff, then the node is added to a cluster. If all predecessors or successors are also clusters, the cluster is merged with the one with which it is most highly correlated. If a cluster containing only one element cannot be merged, it is deleted and its relations pass over to its neighbors. Isolated clusters which are not connected to other nodes or clusters are also deleted.

This method leads to simpler models than methods like the Heuristics Miner (Frèrejean, 2008; Reimann, Frèrejean, & Thompson, 2009). Therefore, “the Fuzzy Miner is suitable for mining less-structured processes which exhibit a large amount of unstructured and conflicting behavior” (Process Mining Group, 2009, June 17).

6 Method

6.1 Participants

For the purpose of this study, we reanalyzed the data of another study (Schoor & Bannert, 2011) in which 200 university students participated. The aim of the original study was to analyze the relation of motivation, knowledge acquisition and learning activities during CSCL. We reanalyzed the data of the best and worst 10% of the dyads in group performance (development of a handout) in order to get extreme groups. As the cutoff handout score for the low-achieving group was reached by two dyads, this resulted in the 10 most successful and the 11 least successful dyads (N = 42 participants). Handout scores of all 21 dyads as well as their z value in the original sample are listed in table 1.

The participants were mainly students of educational science (26%) or media communication (29%). There were 5 students of European studies, 4 studied linguistics, additional 4 politics. Others were studying economics, engineering, sports or adult education. The particpants’ mean age was 23.1 years (SD = 3.15). 41% were first-year, 10% second-year, 14% third-year and 36% fourth-year and higher students. There were more female (67%) than male (33%) participants.

6.2 Procedure

Participants’ task was to collaboratively develop a handout on a statistical topic. In an individual part, they first had one hour to read their learning text and to elaborate an individual handout. After a break of about ten minutes, the collaborative part started during which the participants communicated via chat and a common editor with their partner in order to produce a joint handout. They worked for about 90 minutes in dyads whose partners had read different individual texts in order to create a kind of resource dependency (Johnson & Johnson, 1992) and different viewpoints. Their instruction was to develop a joint handout about the test of significance for a (fictive) course presentation which should contain the outline of their talk and the main definitions. The participants knew that they had got different learning texts. Moreover, they got the following suggestion for a procedure: First present each other the respective individual handout, then agree upon a joint outline, fill this outline with the necessary definitions, check them, ask questions of understanding. Participants’ motivation and knowledge before and after both parts of the study were measured and their learning activities were logged.

6.3 Handout scores

The quality of the handouts was rated by a trained rater according to the following criteria: selection of matters, their correctness, their concise description, structuring of the outline. Points were taken for unnecessary matters. All in all, 36 points could be reached. In a previous study (Schoor, 2010), the inter-rater reliability was Cohen's $\kappa = .63$ which is substantial (Landis & Koch, 1977).

Table 1 also includes the scores of the individual handouts which the participants developed before the collaborative phase. A *t* test showed that participants in high-achieving dyads got significant higher handout scores already in the individual handouts ($t(40) = -2.75$, $p < .01$, $d = 0.85$). However, we did not consider this to be a major problem for the purpose of our study as a higher prior performance might provoke other regulatory activities (Akyol, Sungur, & Tekkaya, 2010; Moos & Azevedo, 2009; Pressley, 1994) as well as other regulatory activities might result in higher performance (e.g. Azevedo, et al., 2004). In both cases, there should be differences in our extreme groups regarding their regulatory activities.

6.4 Learning text and course management system

The participants worked on our course management system Moodle (version 1.6). There they got an editor for the individual part. During the collaborative part, they shared a chat and an editor with their learning partner.

As learning texts, participants got one of two short introductory texts on the test of significance. Learning partners of a dyad got different learning texts. Text 1 consisted of two subchapters from Bortz and Döring (2002) while text 2 comprised one chapter from Sedlmeier and Köhlers (2001). Both texts explained about the same matters, but in a different way. Both texts were comparable in length and difficulty.

6.5 Coding of learning activities

The log files of chat and editor were segmented according to the segmentation rules by Strijbos, Martens, Prins, and Jochems (2006) and coded. For the purpose of this study, we re-coded the data of 10 high-achieving and 11 low-achieving dyads via a coding scheme developed for this study (see table 2). The coding scheme is derived from our theoretical framework and the coding scheme for self-regulated learning by Bannert (2007). We included orientation and goal setting, planning, task processing (work on the task), evaluating, monitoring and coordination (controlling of task processing). Moreover, we included motivation categories (positive and negative motivation, regulation of motivation) as in many conceptions of self-regulated learning, motivation constitutes a substantial part (e.g. Boekaerts, 1996; Zimmerman, 2000). The specific setting of the study with an individual pre-phase and the results from the original study (Schoor & Bannert, 2011) led us to include additional categories for the appraisal of the partner and for the approach during the individual phase. Coding was done by two independent raters. Their concordance was Cohen's $\kappa = .69$ (substantial according to Landis & Koch, 1977). In cases of non-congruence, the final category was negotiated. Segmenting took about 1 hour per dyad, coding about 3 hours per dyad.

6.6 Process mining parameters

To analyze the log files, we used the software ProM 5.0 (2008). The categories “other” and “not categorizable” were excluded, as we wanted to concentrate on task-related interaction. We used a maximal event distance of 5 with a linear attenuation as in the chat logs 5 segments seemed to be the maximum distance between two immediately related segments. For unary significance, we included both frequency and routing significance with weighting 1. For binary significance, both frequency and distance significance were used and weighted 1. For binary correlation, we used proximity correlation, and the originator correlation with weighting 1. Originator correlation was first inverted in order to give a subsequent event by the learning partner a greater weight than an event of the same learner, as this change of originator indicates a direct interaction. For conflict resolution, we used the default values (preserve threshold = 0.6, ratio threshold = 0.7) as we did for edge filtering (edge cutoff = .2, utility ratio = .75). The significance cutoff was set to .5 in order to preserve only the more important events.

For high-achieving dyads, a total number of 1488 events was analyzed. The data for low-achieving dyads consisted of 1732 events.

7 Results

Table 3 displays the resulting frequency of categories. We tested whether the high-achieving and low-achieving dyads differed in their activities. As some cells of the contingency table had a too small expected frequency, we used Fisher’s exact test instead of a chi-square test. We found no significant differences ($p > .07$, Fisher’s exact test, two-sided). Concerning the frequency of single activities, we noted relatively high frequencies of *coordination (before action)*, *work on task in the chat* and *monitoring of the group*. *Orientation*, *planning* and *evaluating* were executed only half as often at maximum.

In a next step, we analyzed the process of high-achieving and low-achieving dyads separately via Fuzzy Miner (Günther & Van der Aalst, 2007) implemented in ProM 5.0 (2008). Figure 2 and figure 3 display the resulting models for high-achieving respectively low-achieving dyads. In order to obtain a kind of split-half-reliability, we repeated these analyses for the 5 most successful resp. the 5 least successful dyads. The obtained models were very similar to those in figure 2 and 3.

We see in both high-achieving and low-achieving group processes a double loop of *coordination* (COOR-G), *working on the task* (COG-C) and *monitoring* (MON-G). Interestingly, it is not a loop of working on the task – monitoring – coordination – working on the task what we could have expected from a theoretical point of view, but two loops working on the task – coordination – working on the task and working on the task – monitoring – working on the task. Additionally, in both high-achieving and low-achieving dyads, the *appraisal of the partner’s cognition* (APC) seems that important that it remained outside the cluster of less significant activities. This is not due to a frequent occurrence of this activity (compare table 3) but due to its routing significance. This means that at this node the process either forks or merges. In our case, it seems that the process merged. For high-achieving dyads, above that only *regulation of motivation* remained outside the cluster, also due to its routing significance. For low-achieving dyads, there remained more significant events, namely *working on the task in the handout*, *coordination after action*, and *negative motivation*.

An example for the double loop of work on task, coordination and monitoring is the extract of a log file of a high-achieving dyad in table 4. The extract starts 10 minutes after the beginning of the collaborative phase. The two learning partners had presented their individual handouts and were now trying to develop the joint handout. They did not make a general plan of their procedure but just “jumped” directly into the work on the task. After having talked about the first steps of collapsing several paragraphs (COG-C), they realized that somebody should do the work in parallel and coordinated that. Vpn255 suggested that Vpn220 did it and she agreed (COOR-G). She wanted to make sure she had understood the consensus about the first paragraphs and repeated it. She also wanted to make sure that the consensus was to use Vpn255’s outline (COG-C). Then she changed to a meta-level by talking about the good parts of both individual handouts. Vpn255 agreed and completed (MON-G). Then they went back to working on the task and fine-tuned the introduction (COG-C). After that, Vpn255 asked Vpn220 to always save the changes which was the sign for Vpn220 to start writing which she announced (COOR-G). After the first saving (COG-H), the extract ends with Vpn255’s statement that the introduction is finished trying to move to the next paragraph (COOR-G).

In this example, we also see the idea of the Fuzzy Miner to abstract from too fuzzy information. Not all sequences of categories displayed in the example found their way into the resulting model but only important ones which occurred more frequently.

Table 5 contains the log file extract of a low-achieving dyad, also on the loop of monitoring, working on the task, and coordination. This dyad took more than half an hour to present their respective individual handouts and to produce a joint first paragraph which was easy because both individual versions were similar. However, there was much off-topic talk and talk about technical problems in between. Like the high-achieving dyad, this dyad did not make a plan and just began by changing the handout. Work on the second paragraph started with Vpn166 to say that she did not understand Vpn054’s point (MON-G) and she wanted to delete it (COG-C). At about the same time, Vpn054 stated she needed to have a look at it (COOR-G). In the meantime, Vpn166 corrected herself by saying that the problem was not her missing understanding (MON-I) but that she did not know whether this point was important (MON-G). Vpn054 realized that she was talking about the gross planning of the analysis (COG-C) but admitted that she did not know whether this was important (MON-G). They discussed about it and agreed that for novices this indeed might be important. Vpn054 reopened the dialogue by asking for the coordination of the next step. Vpn166 suggested to leave Vpn054’s (discussed) second point but asked what to do with her second point (COG-C). They realized that this was similar to Vpn054’s third point (MON-G) and Vpn166 decided to leave Vpn054’s third point but to discard her own second point (COG-C). This time, Vpn166 urged to the next step. Vpn054 had not followed her decision and suggested that she included Vpn166’s two bullet points (her third point) in her second point (COOR-G). In the meantime, Vpn166 suggested to include the kinds of errors after Vpn054’s third point (COG-C). This was more important to her than the inclusion of her second point. She wondered whether the errors should be subdivided (COG-C) while Vpn054 was still working at the old point. Vpn054 now wanted to make sure that she deleted the discussed points stemming from Vpn166 (COOR-G) and suggested to put the errors on this place (COG-C). Then she also agreed on the subdivision of this point (COG-C). The both seem now finally to be thinking about the same things again. Vpn166 agreed (COG-C) and Vpn054 announced that she would implement what had just been discussed (COOR-G).

In comparison with the high-achieving dyad, this log file extract shows a much faster change of categories. The learning partners seem to be more volatile without real misunderstandings. However, this impression is not reflected in the Fuzzy Miner model. A measure for this would be the strength of category self-loops. As both models contain corresponding self-loops, the impression of a more volatile low-achieving dyad should be considered carefully.

8 Discussion

The purpose of this study was to analyze social regulation in an exploratory way. Additionally, we wanted to evaluate process mining as a tool for analyzing CSCL processes and to gain first insights into the temporal sequence of social regulation.

To sum up: we found no differences between high-achieving and low-achieving dyads in the frequencies of regulatory activities. Moreover, we found no major differences in the process models of high-achieving versus low-achieving dyads. Apparently, there were no differences at all between high-achieving and low-achieving dyads. Concerning the frequency results, this finding is contrary to results from SRL and to the results of Winters and Alexander (2011) that show a positive relationship between regulatory activities and performance. However, Perera et al. (2009) also could not find a relation between frequencies and sequences of activities and performance of CSCL groups. Maybe the analyzed activities in both Perera et al.'s (2009) and in our study were not optimal. As Winters and Alexander (2011) found significant relations of performance with the activity *strategy*, this might be a better starting point for further research. This could also be related to the impression of a greater volatility in the log file extract of the low-achieving dyad. However, Winters and Alexander (2011) also found a correlation of performance and monitoring, in which activity our dyads differed neither.

An interesting result is that of a double loop of monitoring, working at the task, and coordination with working at the task as central activity which is connected to both coordination and monitoring. The log file extracts show that both coordination and monitoring were followed by a discussion at the content level before monitoring or coordination occurred. It seems that for this task monitoring was often verified at the content level. And this then led to coordination and then to the next topic at the content level. This might be due to the metacognitive character of the task: the participants had to create a handout about a topic. This included, for example, selection and evaluation of relevant content which is per se of metacognitive nature. Therefore, it was sometimes difficult to differentiate between regulatory activities like evaluating and activities on the task level, as the task was itself at a meta-level. A consequence for further research would be to either choose a task less metacognitive or to explicitly integrate into the theoretical framework and code different levels of cognition and regulation.

Apart from this constraint by the nature of the current task, the results of this study might, however, indicate that in social regulation there is no simple closed loop of cognitive activities, monitoring and controlling (that influences operation and in our study was conceptualized as coordination) as assumed by models of self-regulation and self-regulated learning (e.g., Carver & Scheier, 2005; Winne & Hadwin, 1998). The fact that in social regulation at least two different processes (the activities of both learners) interact with each other and form another process on the group level seems to make it difficult to observe a classical closed feedback loop. For theorizing as well as for empirical observation, this finding means that both the different levels (individual vs. group level) and their interaction with each other and the interaction of the different individual processes have to be taken into account when analyzing social regulation. Thereby, the present study points to an important issue for further research.

Another striking result was that orientation, planning and evaluation belonged to the cluster of insignificant events. This was due to their infrequent occurrence in both high-achieving and low-achieving dyads. Concerning orientation, this result is comparable to results of e.g. Bannert (2007) for SRL or De Jong et al. (2005) for both SRL and CSCL. It seems that all dyads did not plan in before but just "jumped" into the collaboration and coordinated their group process on the fly. This seems to parallel results from SRL that many students do not act strategically spontaneously (e.g. Bannert, 2007, 2009). Therefore, it is questionable whether our theoretical framework should contain these regulatory activities at the group level. However, in studies on individual SRL, these regulatory activities distinguish between high-achieving and low-achieving learners (Bannert, 2007). Therefore, these activities might be important for a sound performance also on the group level although our participants did not show them. Further research is needed to justify the inclusion of these activities into models of socially regulated learning.

Concerning process mining as a tool for CSCL research, we have to conclude that this kind of analysis can provide the researcher with useful insights into the very process of (CSCL) learning. We can therefore recommend these methods for further analyses. Therein, this study contributes to our repertoire of research methods for analyzing temporal sequences. However, we have to mention that the method used in this study is to some extent subjective in such as that there exist no standards for values which have to be specified during analysis and which influence the results of process mining (all thresholds reported above). It is subjective to the researcher to choose reasonable values. Furthermore, we analyzed only a small sample size (due to the effort of coding log files). Therefore, the obtained models have to be considered carefully, as in process mining, a model is always generated. Additionally, we so far used only descriptive methods to analyze the CSCL process. In further research, when there are stronger assumptions about the temporal sequence of regulatory activities during CSCL, hypothesis testing methods could be applied.

Another reasonable next step would be to further develop the theoretical framework and the coding scheme derived from it. It would be interesting to distinguish other-regulation and socially-shared regulation also in different kinds of regulatory activities. Additionally, it could be interesting to code whether the negotiation of regulation was successful or not (compare the valence coding of judgments of learning, Azevedo, 2009).

Concerning pedagogical and technological consequences, the comparable lack of orientation, planning and evaluation could be a starting point for further support measures. Encouraging CSCL groups to share their individual orientation, planning and evaluation in order to come to a socially-shared notion about regulation and the learning process could be both: part of the pedagogical design and part of the used software itself.

Acknowledgments

We thank Peter Reimann, who gave us valuable advice for data analysis with ProM 5.0 and the DFG (German Research Foundation) for funding (BA 2044/5-1).

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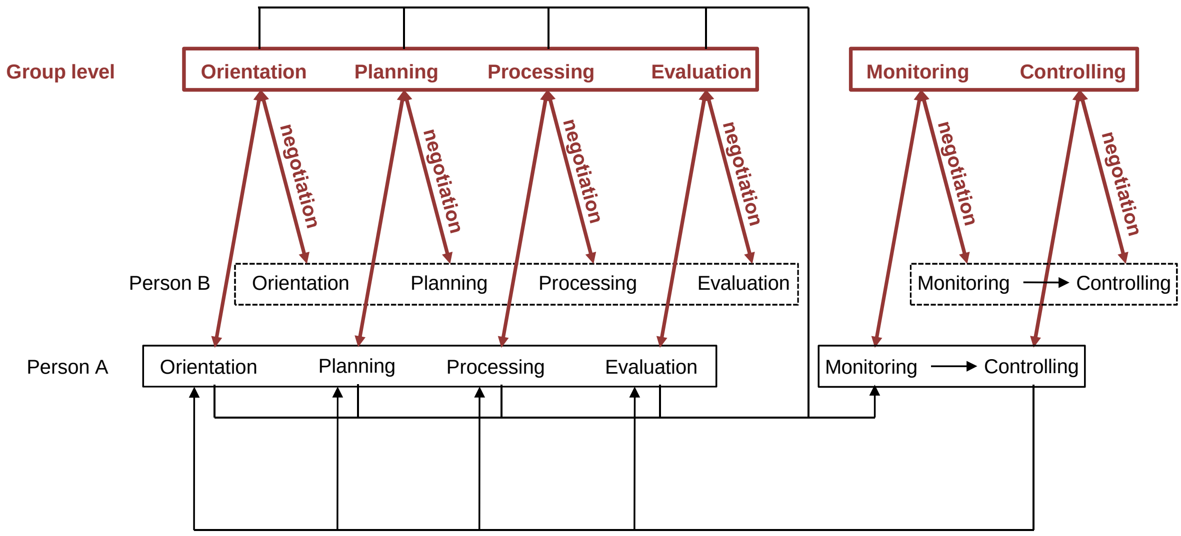
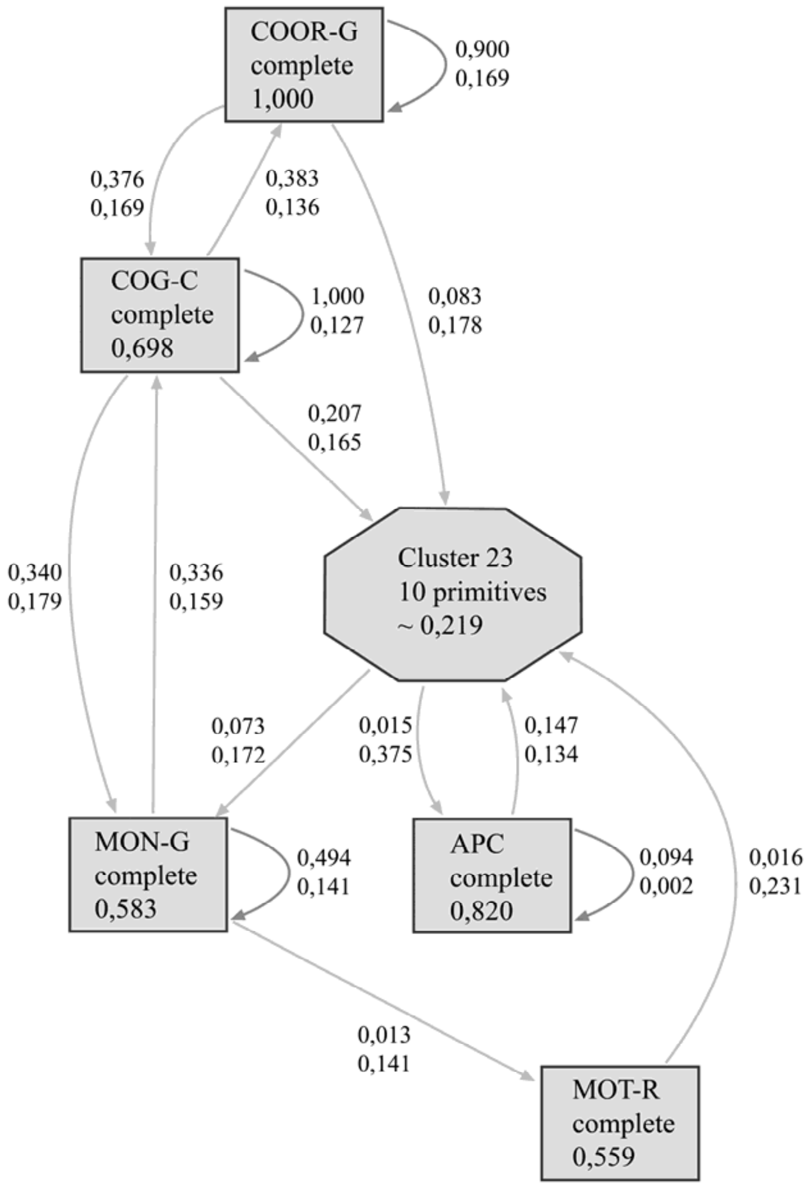
Figure Captions

Figure 1. Theoretical framework.

Figure 2. Process of successful groups.

Figure 3. Process of less successful groups.


Group level
Orientation
Planning
Processing
Evaluation
Monitoring
Controlling
negotiation
negotiation
negotiation
negotiation
negotiation
negotiation
Person B
Orientation
Planning
Processing
Evaluation
Monitoring
Controlling
Person A
Orientation
Planning
Processing
Evaluation
Monitoring
Controlling



APC	Appraisal of partner's cognition
COG-C	Work on task in chat
COOR-G	Coordination (before action)
MON-G	Monitoring of group
MOT-R	Regulation of motivation

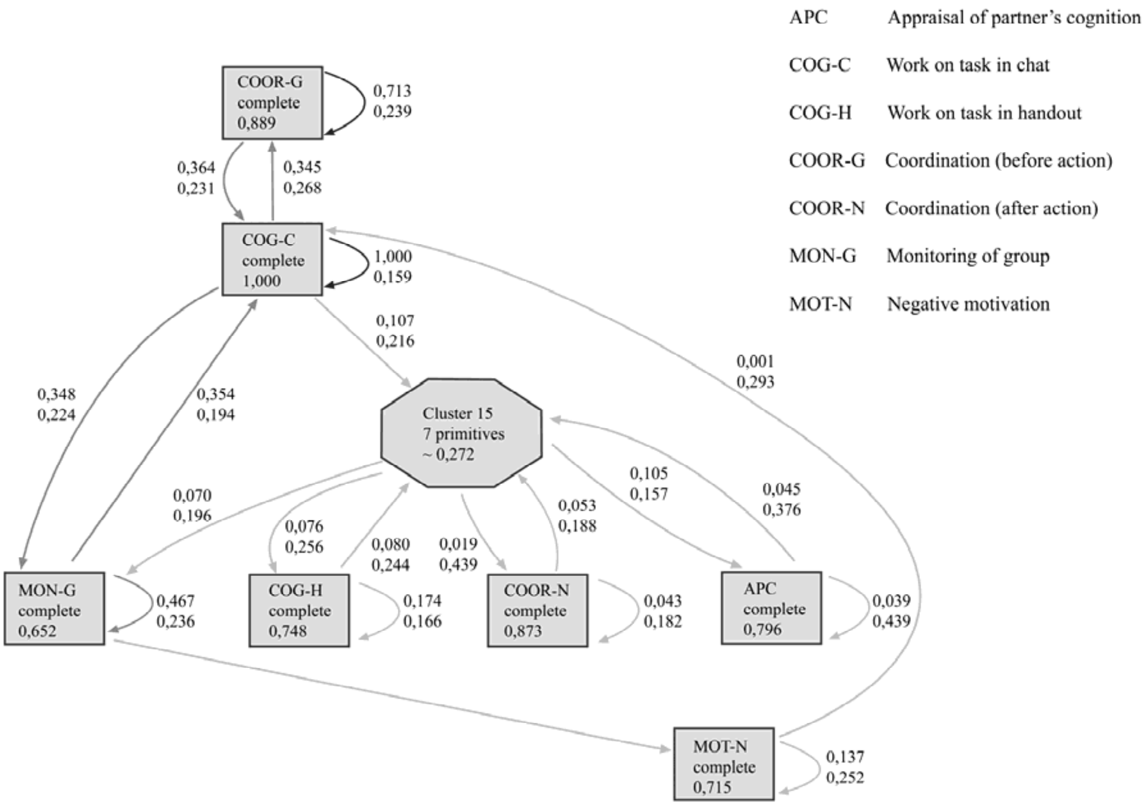

COOR-G
complete
0,889
0,713
0,239
0,364
0,231
0,345
0,268
COG-C
complete
1,000
1,000
0,159
0,107
0,216
0,001
0,293
0,348
0,224
0,354
0,194
Cluster 15
7 primitives
~ 0,272
0,070
0,196
0,076
0,256
0,080
0,244
0,019
0,439
0,053
0,188
0,105
0,157
0,045
0,376
MON-G
complete
0,652
0,467
0,236
COG-H
complete
0,748
0,174
0,166
COOR-N
complete
0,873
0,043
0,182
APC
complete
0,796
0,039
0,439
MOT-N
complete
0,715
0,137
0,252
APC Appraisal of partner's cognition
COG-C Work on task in chat
COG-H Work on task in handout
COOR-G Coordination (before action)
COOR-N Coordination (after action)
MON-G Monitoring of group
MOT-N Negative motivation

Table Captions

Table 1. Handout scores (absolute and *z*-value within original sample) of successful and less successful dyads during collaborative phase as well as individual handout scores after the individual phase.

Table 2. Coding categories.

Table 3. Frequencies of categories in successful and less successful groups as well as overall.

Table 4. Log file extract of a successful group.

Table 5. Log file extract of a less successful group.

Table 1. Handout scores (absolute and *z*-value within original sample) of successful and less successful dyads during collaborative phase as well as individual handout scores after the individual phase.

	Individual handout score Partner 1	Individual handout score Partner 2	Group handout score	*z*-value group handout score
Less successful dyads				
Dyad 035	0.0	16.0	3.0	-2.68
Dyad 081	-1.0	13.0	4.0	-2.51
Dyad 061	3.0	13.5	5.5	-2.26
Dyad 007	2.0	13.0	6.5	-2.09
Dyad 085	6.0	10.0	9.5	-1.58
Dyad 091	3.0	8.5	10.0	-1.49
Dyad 096	18.0	4.0	10.0	-1.49
Dyad 066	6.0	29.5	11.0	-1.32
Dyad 068	5.0	22.5	11.5	-1.23
Dyad 023	1.0	14.0	12.0	-1.15
Dyad 079	2.0	4.0	12.0	-1.15
Successful dyads				
Dyad 038	1.0	13.0	27.5	1.49
Dyad 087	0.0	21.5	27.5	1.49
Dyad 092	17.0	25.0	28.0	1.58
Dyad 043	9.0	22.5	28.5	1.66
Dyad 120	14.5	27.0	28.5	1.66
Dyad 004	6.0	26.0	29.0	1.74
Dyad 013	8.0	22.0	29.5	1.83
Dyad 090	11.5	24.0	29.5	1.83
Dyad 017	14.0	21.0	31.0	2.09
Dyad 012	6.0	29.0	32.0	2.26

Table 2. Coding categories.

Category		Indicators
Social regulation		
OGS	Orientation and goal setting	Task clarification, overview over texts
PLAN	Planning	(Longer-term) planning of proceeding
COG-C	Work on task in chat	Talking about what to include in the handout
		Talking about the subject matter
COG-H	Work on task in handout	Changing the handout
EVA	Evaluation	Checking and evaluating of (preliminary) handout
MON-G	Monitoring of group	Monitoring the group's learning / handout development progress
MON-I	Monitoring of one self	Monitoring one's own learning progress
COOR-G	Coordination (before action)	Allocating sub-tasks, arranging task processing
COOR-N	Coordination (after action)	Announcing that one has done some sub-task (without having it arranged beforehand)
Additional		
APC	Appraisal of partner's cognition	Guessing of the partner's thinking
APM	Appraisal of partner's motivation	Guessing of the partner's motivation
AIP	Approach during individual phase	Explanations about own proceeding during the individual phase
Motivation		
MOT-P	Positive motivation	Talking about being motivated
MOT-N	Negative motivation	Talking about being not motivated
MOT-R	Regulation of motivation	Trying to enhance the group's motivation
Other		
OTH	Other	Off-topic talk, comments on technique
NCA	Not categorizable	Not interpretable comments

Table 3. Frequencies of categories in successful and less successful groups as well as overall.

	10 successful dyads ($N = 20$)		11 less successful dyads ($N = 22$)		Overall ($N = 42$)	
Social regulation						
Orientation and goal setting (OGS)	147	(7.3%)	131	(5.5%)	278	(6.3%)
Planning (PLAN)	39	(1.9%)	43	(1.8%)	82	(1.9%)
Work on task in chat (COG-C)	326	(16.1%)	440	(18.6%)	766	(17.5%)
Work on task in handout (COG-H)	144	(7.1%)	156	(6.6%)	300	(6.8%)
Evaluation (EVA)	31	(1.5%)	37	(1.6%)	68	(1.5%)
Monitoring of group (MON-G)	247	(12.2%)	322	(13.6%)	569	(13.0%)
Monitoring of oneself (MON-I)	78	(3.9%)	61	(2.6%)	139	(3.2%)
Coordination (before action) (COOR-G)	395	(19.5%)	458	(19.4%)	853	(19.4%)
Coordination (after action) (COOR-N)	27	(1.3%)	28	(1.2%)	55	(1.3%)
Additional						
Appraisal of partner's cognition (APC)	4	(0.2%)	7	(0.3%)	11	(0.3%)
Appraisal of partner's motivation (APM)	1	(0.0%)	0	(0.0%)	1	(0.0%)
Approach during individual phase (AIP)	28	(1.4%)	29	(1.2%)	57	(1.3%)
Motivation						
Positive motivation (MOT-P)	8	(0.4%)	3	(0.1%)	11	(0.3%)
Negative motivation (MOT-N)	9	(0.4%)	9	(0.4%)	18	(0.4%)
Regulation of motivation (MOT-R)	4	(0.2%)	8	(0.3%)	12	(0.3%)

Table 3 continued.

	10 successful dyads (*N* = 20)		11 less successful dyads (*N* = 22)		Overall (*N* = 42)	
Other						
Other (OTH)	524	(25.9%)	613	(25.9%)	1137	(25.9%)
Not categorizable (NCA)	11	(0.5%)	21	(0.9%)	32	(0.7%)
Overall	2023	(100.0%)	2366	(100.0%)	4389	(100.0%)

Table 4. Log file extract of a successful group.

Originator	Timestamp (hh:mm:ss)	Segment	Coding
		[dyad has presented their respective individual handouts and is now talking about the joint outline]	
Vpn255	11:27:05	2.1 and 2.2 together	COG-C
Vpn255	11:27:28	2.5 and 6 and maybe 4	COG-C
Vpn220	11:27:52	yes	COG-C
Vpn220	11:27:56	for example	COG-C
Vpn255	11:28:05	Do you change the handout?	COOR-G
		For only one person at a time is allowed to save it	OTH
Vpn220	11:28:21	yes I can do it	COOR-G
Vpn220	11:28:37	So you mean 2.1 + 2.2 and 2.4+2.5+2.6?	COG-C
Vpn255	11:28:53	Exactly	COG-C
Vpn255	11:29:10	Then we include your 1.2 into 2.1	COG-C
Vpn220	11:29:38	okay but before that: we take your outline?	COG-C
		Do we include anything of mine?	COG-C
Vpn220	11:30:32	Concerning the matter, I think that in my handout the “beginning” of such a test is better described.	MON-G
		In yours is better that you better described the end, the actual analysis.	MON-G
Vpn255	11:30:40	I think the conclusion is also good	MON-G
Vpn255	11:31:26	that’s right, your text seems to me to be of a higher level	OGS
Vpn220	11:31:36	okay, let’s start at the beginning	COOR-G
Vpn220	11:31:41	Introduction:	COG-C
Vpn220	11:31:50	I think yours is good	MON-G
Vpn220	11:32:04	could be completed with mine	MON-G
Vpn255	11:32:24	ok	MON-G
Vpn255	11:33:08	simply as 3rd item into the introduction	COG-C
Vpn220	11:33:14	2nd part: we take yours as basis	COG-C
		and this is completed with mine at the right points	COG-C
		while yours is a little bit compressed	COG-C
		(we just talked about that)	MON-G
Vpn220	11:33:24	exactly	COG-C
Vpn255	11:33:57	ok... Do you always save so that I see the changes?	COOR-G
Vpn220	11:34:09	okay	COOR-G
Vpn220	11:34:25	okay, I’ll start,...	COOR-G
		however, I don’t know how fast I will be ;)	COOR-G
Vpn255	11:34:55	:)	OTH
Vpn220	11:36:04	[saves the handout with changes]	COG-H

Vpn255	11:38:00	ok, introduction finished	COOR-G

Note. COG-C = Work on task in chat. COG-H = Work on task in handout. COOR-G = Coordination (before action). MON-G = Monitoring of group. OGS = Orientation and goal setting. OTH = Other.

Table 5. Log file extract of a less successful group.

Originator	Timestamp (hh:mm:ss)	Segment	Coding
		[dyad has presented their respective individual handouts and has produced a joint 1st paragraph with many technical and off-topic talk in between and is sow about to start working on the 2nd paragraph]	
Vpn166	12:02:07	your 2nd point... I don't understand it	MON-G
Vpn054	12:02:14	I'll have a look	COOR-G
Vpn166	12:02:16	Can we omit it?	COG-C
Vpn166	12:02:48	So, I understand it	MON-I
Vpn166	12:02:53	But is it important?	MON-G
Vpn054	12:02:58	But that's the gross planning how to start the analysis	COG-C
Vpn054	12:03:05	don't know whether it's important	MON-G
Vpn166	12:03:19	yes, that's true	COG-C
		but is it interesting for somebody who just wants to get an insight into what this is?	MON-G
Vpn054	12:03:24	For people who didn't read it maybe yes	MON-G
Vpn166	12:03:28	mhm	NCA
Vpn166	12:03:31	Very well then	MON-G
Vpn054	12:03:49	And now?	COOR-G
Vpn166	12:04:01	Where could we smuggle my 2nd point into?	COG-C
Vpn166	12:04:07	We just leave your 2nd point	COG-C
Vpn054	12:04:41	Well, your second point is similar to my third, just shorter	MON-G
Vpn166	12:04:41	I see it	MON-G
Vpn054	12:04:46	:-)	OTH
Vpn166	12:04:51	Exactly, therefore discard	COG-C
Vpn166	12:04:54	We leave your third point	COG-C
Vpn166	12:05:00	I just saw it, too	MON-G
Vpn166	12:05:04	ok, resume	COOR-G
Vpn054	12:05:45	Shall I include these two bullet points there?	COOR-G
Vpn166	12:05:56	But maybe we could mention the kinds of errors after your 3rd point?	COG-C
Vpn166	12:06:04	No, you don't need to, rather the errors	COG-C
Vpn166	12:06:23	just don't know whether we should subdivide them?	COG-C
Vpn054	12:06:31	well, then I'll delete them?	COOR-G
		Won't I?	COOR-G
		And then the errors get their place there	COG-C

Vpn054	12:06:50	yes, I'd leave your outline of the kinds of errors	COG-C
Vpn166	12:07:24	ok	COG-C
Vpn054	12:07:39	well, then I'll do that what we just discussed	COOR-G

Note. COG-C = Work on task in chat. COOR-G = Coordination (before action). MON-G = Monitoring of group. MONI-I = Monitoring of one-self. NCA = Not categorizable. OTH = Other.