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Analyzing and Supporting Collaboration in Cooperative Computer-Mediated Communication

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Abstract. Two methods for fostering collaborative behavior are compared: a feedback-mechanism to scaffold collaborative behavior, and use of distributed learning resources. Based on recent research on what constitutes effective collaboration behavior, we developed a coding scheme to categorize learner-learner interaction as collaboration. In a collaboration environment for learner dyads specifically implemented to test our hypotheses, a human observer identified, in parallel with students' interactions, instances of real collaboration, and gave online feedback. In the same two-factorial design, we varied the resources available to the partners. The influence of these interventions on outcomes related to knowledge acquisition, problem-solving, group climate and collaborative behavior was tested. Results suggest there are benefits in providing a feedback approach in fostering collaboration and enhancing problem-solving quality.

Keywords: Cooperative Learning, Feedback Research, Problem-Based Learning

APPROACHES TO SCAFFOLDING COLLABORATION

Why does collaboration in learning groups need scaffolding? The main reason is that individuals in a group do not automatically cooperate and act as a group. This is particularly the case for groups where the members have not worked together as a team before, are formed for a comparatively short time, and work under conditions where individual learning goals are predominant. These are all characteristics typical of group work in classrooms and other instructional settings, face-to-face or net-based. Under such conditions, scaffolds are needed in order to get group work going, to mitigate disorientation and reduce cognitive load.

The problem of poor peer interaction is well known in face-to-face (ftf) collaborative learning. With the use of typed, text-based computer-mediated communication this problem is likely to be increased. It is much more difficult to establish, perform and maintain basic cognitive mechanisms like turn taking and grounding. In addition, (and especially) social mechanisms like building positive interrelationships, establishing a group identity etc. are afflicted. One way to address this problem, not discussed any further in this study, is to teach collaboration and communication skills directly, as a pre-requisite for group work (e.g. Rummel, Spada, Hermann, Caspar & Schornstein, 2002). Another, more widely used, approach is to scaffold collaboration.

A number of methods for scaffolding collaboration have been developed. In order to structure these approaches, we suggest the taxonomy depicted in Figure 1. A general distinction is made in this taxonomy between scaffolds that are (instructional) design-based (all decisions are made before the collaboration begins and there is a blueprint for how collaboration will be conducted) and those that are management-based (the major decisions are made based on observations from learners' ongoing interaction, and decisions are made at "run time").

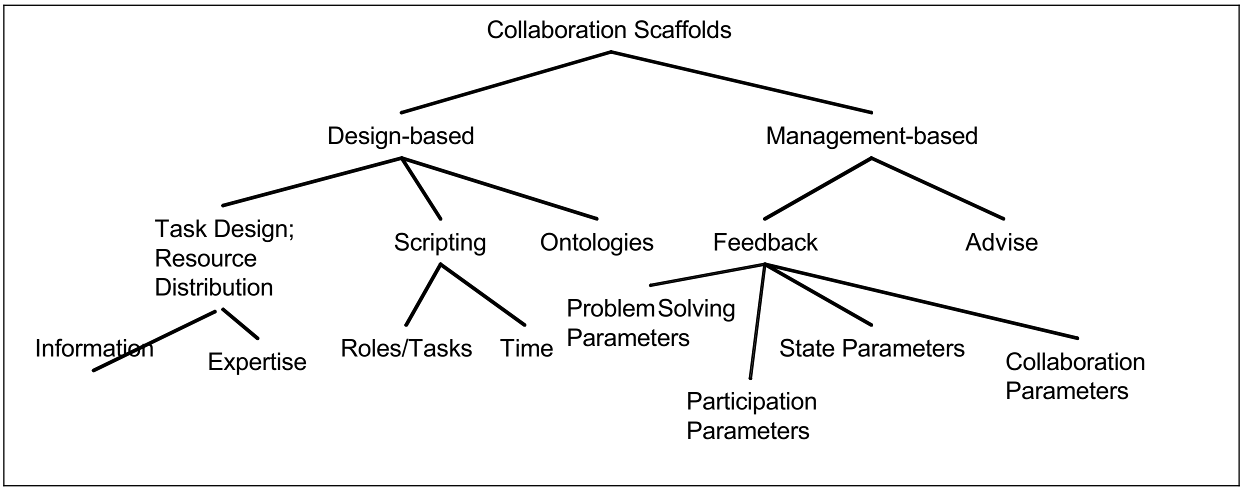


Figure 1: Approaches to Scaffolding Collaboration

Design-based Scaffolding

One method to scaffold collaboration by design involves the selection of specific tasks and resource distributions. Examples are Group Jigsaw (Aronson, 1984), Reciprocal Teaching (Palinscar & Brown, 1984) or Problem-Based Learning (e.g. Barrows, 1985). The rationale behind this approach is that students are forced to collaborate in order to accomplish a goal because of task demands and the manner in which information necessary for accomplishing the task is distributed. An elementary method is to distribute expertise among group members in early stages of group formation (e.g. Hermann, Rummel & Spada, 2001; Rummel et al., 2002). As this is not always possible (for example, when ad-hoc groups are formed) other methods have to be taken into account. A second and more applicable method is to vary resources (for example, the learning material). This method implies that only groups in which members exchange their resources or put them together can successfully complete a (learning) task. Komis, Avouris and Fidas (2003) or Muehlenbrock (2001) provide examples of this methodology by distributing learning resources for collaborative problem solving among learners. In the study of Komis et al. (2003) this intervention did not automatically lead to better learning outcomes (in this case, quality of solutions) compared to dyadic groups with individuals owning all relevant material. However, groups with distributed resources were more active, exchanged more contributions and became more involved in discussion.

Another approach that is often used is *scripting*. Scripting of collaboration (such as assigning specific roles to the members of a team) has proven effective in order to enhance turn-taking (Pfister & Mühlpfordt, 2002; Reiserer, Ertl & Mandl, 2002), elaborate design rationales (Buckingham Shum, 1997), and increase reflection (Diehl, Ranney & Schank, 2001). Reiser (2002) differentiates between two basic mechanisms of these scaffolding techniques: providing structure and problem orientation. Structured communication is one method that can be used to guide learners in terms of an optimized behavioral model (for example problem solving heuristics) or a coordinated exchange between several learners. Furthermore, the attention of learners can be drawn to relevant aspects or elements of a collaborative problem-solving process. Thus, scaffolding and scripting can avoid irrelevant or distracting tasks, strategies and processes.

Scripting as a scaffolding mechanism, however, is not always beneficial. Learner guidance in problem solving can also limit the degrees of learners' freedom. Reiser (2002, p. 263) states: "However, given the importance of connecting students' problem solving work to disciplinary content, skills, and strategies, it may also be important to provoke issues in students, veering them off the course of non-reflective work, and forcing them to confront key disciplinary ideas in their solutions to problems." In addition, structuring of discourse always involves the interruption of natural discourse. Scripting often requires external guidance on sequencing or categorization of contributions without an underlying, empirically proven rationale for the structuring method itself (Reimann, 2003). Providing groups with specific communication and collaboration *ontologies* is the third approach to design-based scaffolding we would like to discuss. Ontologies specify a vocabulary in a kind of notation for expressing information that can be exchanged. A classical example is the IBIS notation (Conklin, 1993), developed to support computer-supported collaborative decision making and organisational memory (for an application to CSCL see, for instance, Zumbach & Reimann, 2002). Dan Suther's work on how external representations affect collaboration is particularly relevant to understanding the importance of ontologies for CSCL. Ontologies are also important for management-based approaches to scaffolding, on which we will focus next.

We think that the design-based scaffolding approaches are particularly appropriate for groups that are working together for the first time and/or whose members have little domain knowledge. In such circumstances, strong external guidance can help members to focus on the task and to avoid extrinsic cognitive load. For groups that are supposed to work together over longer periods of time (such as problem-based learning teams) and/or groups where learning about collaboration is as important as completing the problem solving tasks, collaboration management approaches seem more appropriate.

Collaboration Management

Scaffolding based on collaboration management works with "run time" data gleaned from tracing the (on-line) interaction between group members. A number of approaches have been developed, ranging from the provision of dynamic feedback of participation behavior all the way to complex advice systems (see Soller et al. 2003). Focusing on feedback approaches and our own research, we (Zumbach, Mühlenbrock, Jansen, Reimann & Hoppe, 2002; Zumbach & Reimann, 2003) pursued the analysis of collaborative learning for feedback purposes in order to foster computer supported collaborative learning. In previous work, we used a methodology of tracking user data, aggregating them and feeding them back to groups in order to enrich their available resources by means of their recent collaborative efforts. A major rationale for this method is that a group's recent work is too valuable to be forgotten or unused and that traces of learners' own behavior provide the best source for learning through reflection. We argue that is not sufficient to provide groups with access to shared artifacts; and that what is needed is access to the development of these artifacts over time (problem solving history). In addition, group members need to be provided with information about their interaction and communication behavior, if we are to expect that learning about adequate collaboration and communication is to take place.

Information about learners' collaborative performance can be traced on a number of dimensions. A first dimension is *problem solving*: how does the contribution of a group member change the problem state and contribute to the solution (e.g., Zumbach & Reimann, 2003)? A second dimension is *participation*: how often, in what sequence, around which topics do members contribute to the group's work (Barros & Verdejo, 2000)? A third dimension concerns members' *emotional and motivational state*, or well-being. We (Zumbach et al, 2002, Zumbach & Reimann, 2003) have been able to show that enriching CMC by means of dynamic motivational/emotional parameters of group members helps to positively influence the group climate as well as individuals' motivation (Zumbach, Hillers & Reimann, 2003) and, thus, contributes to groups' well-being functions (cf. McGrath, 1991; McGrath & Hollingshead, 1994). A fourth dimension along which feedback can be provided is *collaboration behavior* proper: how does the action of one group member affect other group members' interaction behavior? Of particular interest in this regard is knowledge sharing (Soller, 2004).

Major challenges for the feedback approach are the (automatic) identification of collaborative acts and avoiding cognitive load problems. While previous research (in particular by Mühlenbrock (2001) and Mühlenbrock and Hoppe (1999), see also Komis et al., 2003 for a similar analysis approach; and Barros and Verdejo, 1999) has shown that collaborative acts can be identified automatically by screening users' interface actions for certain patterns, methodological problems remain. For instance, with these bottom-up approaches it is impossible to identify when a certain behavior does not take place. However, from a communication point of view, *not* reacting in a certain manner can carry important communicative information. Even if such problems were overcome, learners' may still not profit from the feedback because of cognitive load and information overload. Feedback information must be presented (on limited screen space) to a team of people who work on, often complex, tasks in a manner that is easily understandable. Visualisation techniques (e.g. Donath, Karahalios, & Vigas, 1999) become particularly important.

STUDY: COMBINING DESIGN-BASED AND MANAGEMENT-BASED SCAFFOLDING

Design- and management-based approaches to scaffolding can easily be combined and, given that they address different issues and phases of group work, this should probably occur. This study analyses how combining the distribution of learning resources (a design approach) with providing feedback on collaboration behavior (a management approach) affects various parameters of collaboration. Varying both factors in one experimental design allows us not only to assess the effects of combining the two approaches, but also to study interactions between the two factors.

Identifying Collaboration

Analysing collaboration behavior requires us to define units of analysis that capture interaction among group members. (Aggregated) observations on individual participation behavior and assessment of individual psychological states are not sufficient. Barron and Sears (2002) emphasize the role of sequence and interdependence of learner contributions. They suggest that collaboration be regarded as a sequence of different actions and depending reactions (based on a categorization scheme similar to the suggested definition of single actions provided by Barros & Veredejo, 2000). Soller and Lesgold (1999, 2000) also use such a categorization. Leaving a conceptual and abstract level, they give precise suggestions on actions that can be defined as "collaborative events". Soller and Lesgold (1999) define three basic categories of collaborative learning skills (Active Learning, Conversation and Creative Conflict) and eight dependent subskills (Request, Inform, Motivate, Task, Maintenance, Acknowledge, Argue and Mediate) with each specifying detailed actions.

Table 1: Operationalization of collaborative events (as used in this study).

	Action of Person 1	Reaction of Person 2	Reaction of Person 1 (to Person 2)
A1	proposal (related to problem) [1, 2, 3] also: contraproposal [1, 2, 3]	agree/ accept [1, 3, 7]	
		or	
A2		support [1]	
		or	
A3.1		propose a next step [1]	agree/ accept [1, 3, 7]
			or
A3.2			support [1]
			or
A3.3			propose a next step [1]
			or
A3.4			document the proposal [1]
		or	
A4		document the proposal [1]	
		or	
A5.1		query, challenge [2]	modify proposal (for solution) [2]
			or
A5.2			assert or justify or explain (in this case a further positive reaction of person 2 is necessary) [2]
			or
A5.ex			agree, bear out (in this case: no collaboration) [1]
		or	
A6		request time (e.g. for documenting or thinking about) [1]	agree/ accept [1, 3, 7]
		or	
A7		elaborate (active) [2, 6]	
		or	
A8		elaborate (passive) [2, 6]	perform [2]
		or	
A9		ask (in case of lack of understanding) [1, 2, 7]	restate or repeat [2]
B1	ask for help advice [2, 3, 4]	inform [2, 3]	
C1	shift focus to a new aspect [2]	agree/ accept [1, 3, 7]	
		or	
C2		clarify/ negotiate [1, 2, 3]	agree/ accept [1, 3, 7]
D1	encourage partner or peer group [2, 5, 8] support group cohesion [2, 5, 8]		
E1	refer to emotional-motivational process [2, 4, 5, 8]	acknowledge [1, 2, 3, 7]	
		Or	
E2		Answer (referring to contribution) [2, 3]	
F1	coordinate task (steps for solution) [8, 9]	agree/ accept [1, 3, 7]	
		Or	
F2		clarify/ negotiate [1, 2, 3]	agree/ accept [1, 3, 7]
G1	reflect on group processing or analyze group performance [5, 9]	agree/ accept or answer [1, 3, 7]	
		Or	
G2		clarify/ negotiate [1, 2, 3]	agree/ accept [1, 3, 7]
H1	construct meta-knowledge/ reflect on distribution of knowledge [8]	agree/ accept or answer [1, 3, 7]	
I1	drag text block in shared workspace (chat) [2, 5, 7]	continue to work with text	

Notes:[1] cf. Barron & Sears (2002); [2] cf. Soller & Lesgold (2000); [3] cf. Barros & Verdejo (2000); [4] cf. Barron, Martin, Roberts, Osipovich & Ross (2002); [5] cf. Johnson & Johnson (1996); [6] cf. Kneser, Fehse & Hermann (2000); [7] cf. Clark (1996); [8] cf. Reinmann-Rothmeier & Mandl (1999); [9] cf. Welch & Tulbert (2000).

Starting from these definitions and approaches, we developed a coding schema for defining actions to be understood as a “collaborative event” (see Table 1).

Based on interaction chains, Table 1 shows the categories derived from a literature review for dyadic learning in terms of action-reaction-patterns (references to the underlying literature are in the note at the bottom of the table).

Letters A to I in Table 1 describe nine different possible ways to start collaboration (resulting in 26 possible action-reaction chains). All utterances, for example, in category A classify openings with a proposal for a problem solution (or all openings in category F represent coordinative contributions). Each code stands for another chain of interactions and is a unique collaborative event. The following examples should demonstrate the use of the coding scheme: In one of the sessions participant A stated in the chat (translation): “I need more information on the physiological background of depressive disorders. Can you help?“. Participant B answered: “Yes of course. There is something with the neuro-transmitters. According to my resources there might be a relationship between Serotonin, Noradrenalin, Dopamine, Acetylcholine and depressive disorders (…).” The example is according to our coding scheme a B1 event with A asking for help/advise and B sharing requested information. In another example participant B dragged some text into the chat for A who did not have any need for the pasted text because it was not relevant to the problem. In that case no collaborative event has been coded (in case of pasting a “useful” text this would have been an I1 event). Of course one finds longer interaction chains in the data. Our coding scheme does not account for such macro-structures, but breaks them down into elementary components, i.e. “collaborative events”.

Development of a computer supported learning scenario integrating distributed resources and collaboration feedback

Based on the considerations mentioned above, we developed a computer supported learning scenario for dyadic problem solving. The technical platform was an HTML-based interface with several components (see Figure 2). Each learner had (via a Web browser) access to a frame page with several integrated components. The first component was a window containing tasks and the learning material (HTML; left upper corner of Figure 2). The second component was a text editor where solutions to the presented problems had to be developed (left lower corner in Figure 2). The third component was a chat window for possible collaboration purposes (right space in Figure 2). The fourth and last component was an MS Excel© based counter providing feedback about the number of collaborative events (lower right corner).

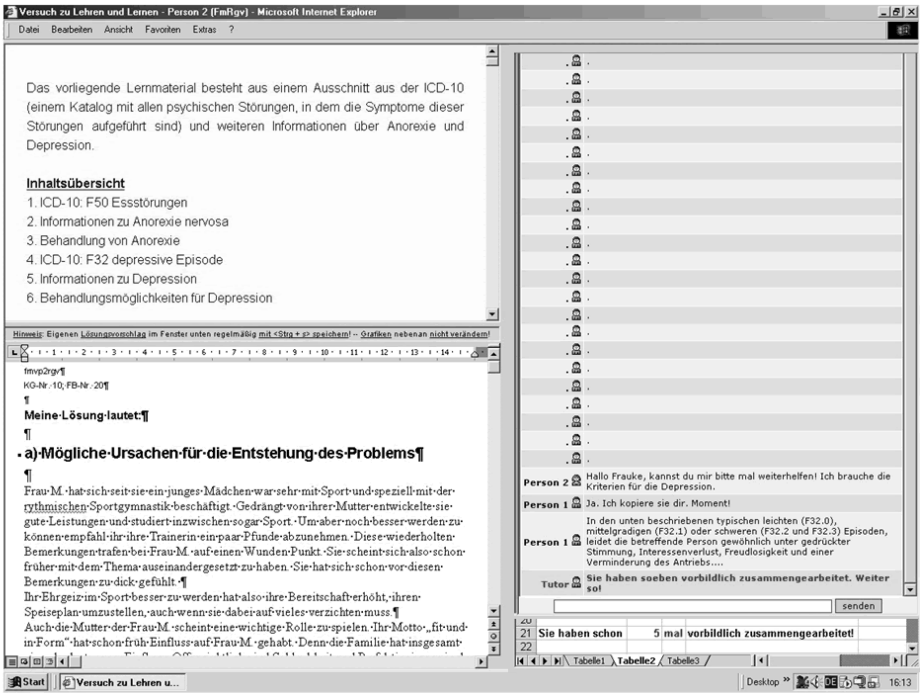


Figure 2: User Interface for individual and cooperative learning.

In order to test the effects of our methodology, we used a cooperative learning scenario in dyads with underlying principles of Problem-Based Learning. For operationalization of our feedback approach on collaborative events we had to use experimenter-based analysis of feedback due to shortcomings of automatic analysis methods related to semantic interpretation of learner-learner interaction. Thus, a trained experimenter who synchronously analyzed discourse in the chat window, monitored learners working in distributed dyads. In the case of a sequence of contributions in accordance with the categories presented in Table 1, the tutor posted the message "You have successfully cooperated! Keep on!" (in the study this was written in German) and the counter of collaborative events was raised. There was no other interference by the experimenter.

Learners were randomly assigned to pairs and conditions and participated synchronously in different rooms. After an introductory pre-test, participants were introduced into the learning environment. We assigned each student the same task, which was to solve a problem in the field of clinical psychology in a written essay (with the text editor). The problem itself was a text only case description about a woman with a co-morbid disorder (depression and anorexia nervosa). Learning objectives with regard to this problem included knowledge about cause, diagnosis, development and therapy of depression and anorexia nervosa as well as relationships between both disorders. The resources to solve the task consisted of passages of a study book for clinical psychology. These passages were digitalized and provided together with the case description as an HTML-document (in the upper left corner of the user interface; see Figure 2).

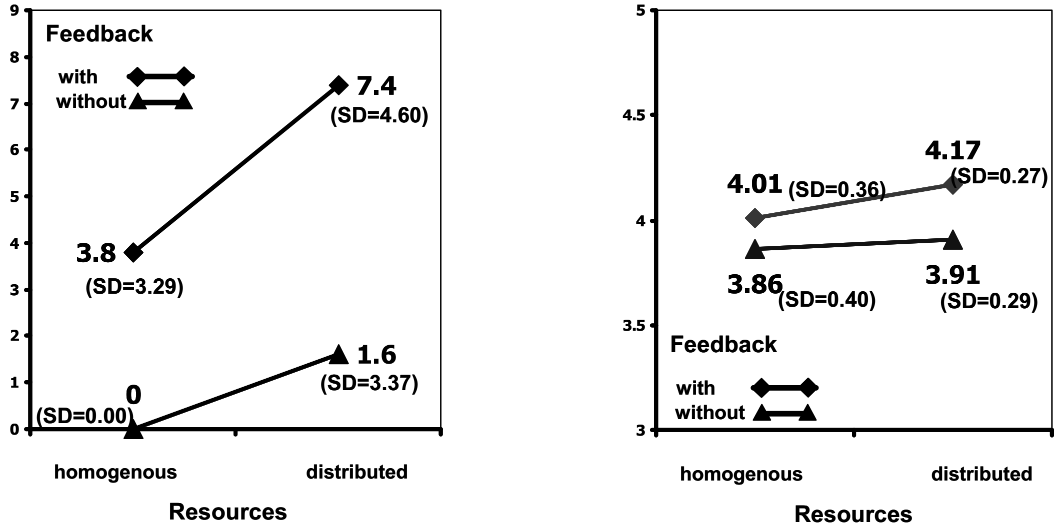
The main purpose of this study was to measure the influence of two basic interventions on the quantity of collaboration and cognitive outcomes as well as group climate: first, the influence of distributed learning resources and second, the availability of feedback on collaborative events (i.e. an underlying 2 X 2 factorial design). The rationale behind this choice was that prior work (e.g. Zumbach & Reimann, 2003; Zumbach, Hillers & Reimann, 2004) has emphasized the role of feedback related to problem solving, participation and state parameters, but not collaboration parameters themselves. Furthermore, there is still need of research on design-based scaffolding related to task design and resource distribution. Thus, the first factor was the variation of the learning resources (homogenous versus distributed). In one condition (homogenous resources), each learner had access to the complete learning material relevant for solving the case. In a second condition, one participant had access only to relevant passages about depressive disorders and the other participant of the dyad to the learning material related to anorexia nervosa. As both parts were single chapters in the underlying textbook, they were simply divided. The second factor was the availability or absence of feedback on collaborative events. In one condition, the dyadic learning groups received feedback as operationalized and described above. In a second condition, the experimenter analyzed collaborative feedback events but no feedback was provided (the visualization was also removed from the user interface). In the introductory part of the experiment, participants received information about their task and the possibility of cooperating with a peer over the computer interface. They were not informed about the different factors of this study (for example, they did not know, in the condition concerned with distributed learning resources, that the other person had different resources that might be additionally relevant for solving the given problem). As each participant was assigned the task of producing an individual case solution, the approach was cooperative rather than collaborative.

Main Results

Our major goal was to show that distributed learning resources as well as collaboration feedback improve collaborative learning and, thus, contribute to learning success, the quality of problem-solving and have a positive influence on group climate. Overall, 40 participants (7 men and 33 women with a mean age of 24.5 years; most of them students at the University of Heidelberg) took part in this study. In a pre-test we assessed participants' prior knowledge with a test related to the learning objectives of the case solution (six open and twenty multiple choice questions with each half assessing knowledge about depression and anorexia nervosa). The same test was used as post-test. In the post-test we also assessed the group climate experienced by participants using an adopted subscale of the Medical School Learning Environment Survey (Lancaster, Bradley, Smith, Chessman, Stroup-Benham & Camp, 1997; Marshall 1978; some sample items are "The learning experience made students feel a sense of achievement.", "The experience of the learning environment made students feel depressed." or "The learning experience made students value themselves."). We expected by means of fostering collaboration to establish a kind of cognitive but also a positive social interdependence. Thus, we expected processes of cognitive as well as social grounding that should contribute to groups' well-being functions (cf. McGrath, 1991). We also took into account the number of collaborative events as well as each participant's quality of problem solution as dependant variables. Overall, participation in this study took about 2 ½ hours with pre- and pos-test lasting about one hour altogether.

Results related to absolute events of collaboration revealed a poor rather than extensive cooperation among individual group members (see Figure 2, left side). In the condition with homogenous resources and no collaboration feedback there was no collaborative event at all. The several interventions led to an increased number of collaborative interactions (Chi-square (df=1) = 3.86, $p<.05$; calculated on group level). The highest amount was in the condition with distributed resources and collaboration feedback. The numbers are, in general, very low (each dyad had about 1 ½ hours time for problem-solving/cooperation). Several aspects might explain this. First, students had to read the case description and scan the learning material (which contained about 8500 words overall; learners were encouraged to read selectively). This took a major part of the available time. Second, the chat limited exchange between students not only to short sentences, but also allowed them to exchange longer paragraphs of the learning material or their own problem solutions. Most interaction chains (considered here as collaborative events) included exchange of major text parts.

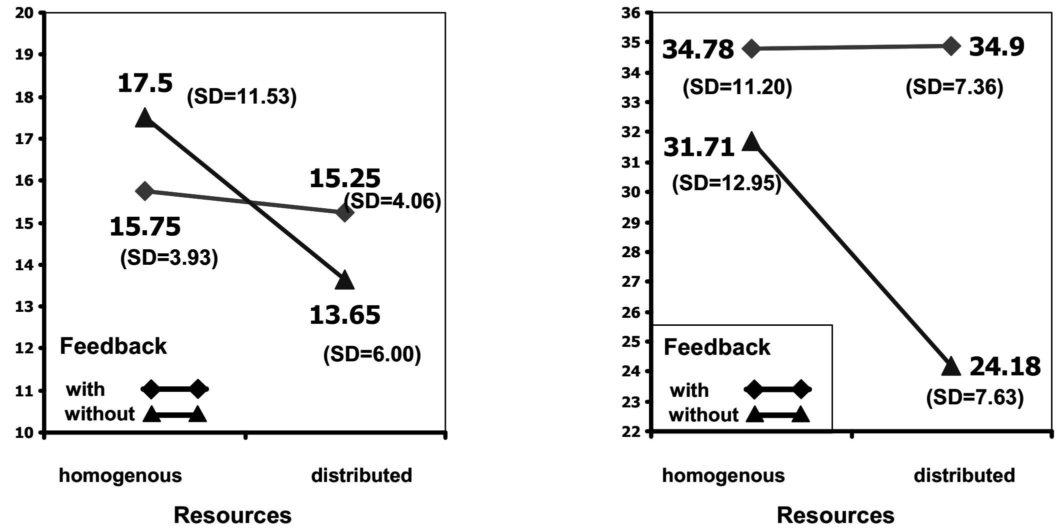
Another dependant variable was the group climate as experienced by the learners. There was no effect of the factor “distributed resources” but a marginal effect of “collaboration feedback” ($F(1, 38) = 3{,}744$, $p < .061$): dyads that received this kind of feedback experienced the group climate better than dyads without this feedback (see Figure 2 right).



Number of collaborative events *Group climate*

Figure 2: Results on collaborative events and group climate.

We were also interested in learning outcomes. Results of the standardized knowledge tests (pre- and post test) were compared in order to compute an overall score of knowledge acquisition from before to after the treatment. Results reveal no significant effects (see Figure 3, left). Participants in the condition with distributed resources and no collaboration feedback received the lowest scores. A lack of collaboration as well as additional learning material (owned by the other partner of the dyad) could explain this.



Knowledge increase *Problem-solving quality*

Figure 3: Results in knowledge tests and problem solving.

For analyzing the quality of problem solutions provided by the participants, we developed an expert solution (including causes, diagnoses and therapy of depression and anorexia nervosa as well as interrelationships between both disorders). Two expert raters compared participants’ case solutions with the expert model using a scoring scheme (r_{corr}=0.97). Participants in dyadic groups with collaboration feedback scored significantly higher than those in groups without feedback (F(1, 38) = 4,687, p< .037; see Figure 3, right). There was no significant effect of distributed versus homogenous resources (F(1, 38) = 1,353, n.s) as well as no significant interaction effect. The following table shows results on correlations of dependant measures.

Table 2: Correlation matrix of dependant variables.

	Number of collaborative events	Group climate	Problem-solving quality	Knowledge (post test)
Number of collaborative events	-	0.56**	0.24	-.02
Group climate	0.56**	-	0.18	-0.17
Problem-solving quality	0.24	0.18	-	0.39*
Knowledge (post test)	-.02	-0.17	0.39*	-

Notes:
Spearman R correlation. * = p<.05; **p<.01

SUMMARY AND DISCUSSION

Based on previous research on CSCL we integrated two major scaffolding approaches into a learning environment in order to assess the combined effects of such approaches, and their interaction effects. There are many approaches that try to describe collaboration in terms of learner behaviour. In the literature review we provided an overview on recent theoretical and empirical approaches. Based on this review we developed a rationale for defining and categorizing chains of interaction as single, collaborative events. Based on these working definitions we conducted a study testing the influence of feedback on collaboration and distributed learning resources in a network-based cooperative learning environment.

In a 2 x 2 factorial experiment we tested the influence of distributed learning resources as well as feedback related to collaboration on outcomes of knowledge acquisition, quality of problem-solving, group climate and number of collaborative events in a network-based cooperative learning scenario. Learners in dyads had to solve a single case following a Problem-Based Learning approach. Results suggest that a distribution of learning resources and feedback about collaboration enhance collaborative behaviour (compared to homogenous learning material and/or no collaboration feedback). Although we could not find an enhancement in knowledge acquisition using a common test format, we were able to show that the feedback approach led to significantly better problem solutions. Results related to group climate also suggest that feedback on collaborative events could foster collaboration itself and, thus, positively influence group climate.

Taken together, results suggest that by distributing learning material, collaboration can be positively influenced but this will have no substantial effect on cognitive outcomes or group climate. In addition, monitoring students interaction behaviour and providing feedback on collaboration triggers further collaborative behaviour and influences problem-solving processes as well as group climate.

Let us try to put this study into a more general perspective. If knowledge is created and re-created primarily through the interactions between people, as a distributed view of cognition suggests, then the analysis of collaboration behaviour constitutes a major prerequisite for the understanding of learning and knowledge. To the extent that collaboration is essential for learning, the analysis of collaboration is essential for meta-learning, for learning about learning. If learners are to be empowered to reflect upon their collaboration behaviour and to become strategically aware collaborative learners, they ought to be provided with concepts and tools for analyzing their collaborative learning. Our approach constitutes a first step in that direction. It is only a first step because in this study we provided minimal information to learners about their collaboration: only the number of 'exemplary collaboration episodes' was fed back to the students. We did not provide conceptual information (the kind of collaboration that was observed) at this stage. Further studies will address this.

Another shortcoming, at least from a pragmatic perspective, is the fact that we used a human observer to analyze learners' interactions. This is clearly not an approach that will scale up to multiple dyads working in parallel or to groups with more than two participants (where communications begin to take place in parallel between sub-groups). The dilemma here is that software, so far, has not surpassed humans in their ability to identify meaningful interaction patterns, or has come close. However, for more or less well-defined discourse areas and small group sizes, it can be expected that semantic techniques, and also statistical text analysis approaches (text mining) can be brought to bear on this task.

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