

How to Support Groups In Learning: More Than Problem Solving.

Peter REIMANN

*Faculty of Education, University of Sydney
Education Building A35, NSW 2006, Australia*

Abstract. The main thesis developed in this chapter is that in order to make progress in managing network-based group collaboration by means of more or less intelligent IT, a broad concept of what makes groups function needs to be at the basis. In reviewing some of the current collaboration management tools, it is concluded that these are often very good in supporting the problem-solving function of groups. Other functions of groups have been identified in psychological and organisational research and some of the more important findings are reported. As these findings stress the importance of helping group members to monitor the group's performance, we report the outcomes of two empirical studies that looked into the effectiveness of providing this sort of monitoring information to groups.

Various forms of learning in groups are increasingly often employed in net-based scenarios where students 'meet' in 'virtual' form independent of location and – in the case of asynchronous communication – independent of time. Building on an extensive knowledge base that results from many years of experience with group learning forms in classrooms [1, 2] as well as from theory building and research contributions [3], the e-learning community has begun to embrace collaborative learning in a major way [4]. In particular, Internet technology has been employed for group learning in various forms [e.g. 5, 6-8].

For groups to realize their potential as a learning resource, more needs to be done than just providing them with a manner to exchange information. Groups have a number of functions and not all of them are related to accomplishing a learning goal, getting a task done or solving a problem. Other functions relate to managing the interaction, keeping the group stable and taking care of individual members' concerns [9]. The move to net-based forms of interaction among group members makes it even more important to attend to these group functions. We will look in this paper at the current state of the art in supporting learning groups and identify areas where support for net-based groups is still missing, but important.

1. Tracking, Mirroring, and Guiding: Approaches to (Intelligent) Collaboration Management Support

Following Jermann, Soller and Muehlenbrock [10] as well as Barros and Verdejo [11] we can distinguish between support that takes the form of *structuring* the collaboration versus *managing* the collaboration. In order to structure collaboration, the designer (or teacher, trainer) can make decisions with respect to a number of parameters: the allocation of *members* to groups (taking into account gender, status or expertise level, for instance) and the selection of *tasks* to work on in groups (well-structured vs. ill-defined for instance) both comprise important didactical aspects [2]. For groups whose interaction is mediated by

communication technology, *media selection* is another important design dimension. Even when using simple classification schemes such as the ‘location x time’ quadrangle, the possibilities become manifold and theoretical models to guide the selection procedure are still in development (such as media richness theory [12] and media synchronicity theory [13]). Related to, but not identical with media selection issues are decisions regarding *representational guidance* [14]. Given that a given representational notation expresses certain aspects of one’s knowledge better than others do, an instructional designer (of collaborative learning activities) should attempt to provide representational tools that incorporate constraints and saliences which fit both task and learner characteristics [15, 16]. A final dimension along which collaboration can be structured focuses on *roles and information flow*; both can be *scripted* to various extents, for instance by assigning group members to roles such as ‘producer’ and ‘reviewer’ and by regulating who can interact with whom over time [17].

Since research has focussed on the issues involved in structuring collaboration for quite some time and much is published, I shall not devote here more space to this topic. Rather, I want to draw your attention to an additional (not alternative) manner of supporting collaboration, one that concentrates on the *management* of collaboration.

1.1 Managing the Collaboration

Managing on-line collaboration by means of intelligent support can take a number of forms (cf. Figure 1). They all require to trace the interaction going on among the team members in some level of detail (*data collection*, [10]) and computing higher level *indicators* to represent the current state of interaction. These indicators can be more or less model-based; for instance, computing a plot of the number of members’ contributions over time involves only a simple transformation of data collected, whereas indicating that a group grapples with ‘unbalanced contribution behaviour’ requires a more complex transformation. In this case, it requires to instantiate a model of interaction (a pattern or procedure describing what ‘unbalanced contribution’ means) with data from the collection step.

Collect Interaction Data	Mirroring/Awareness Tools
Construct Model of Interaction	Metacognitive Tools
Compare with Desired State	
Intervene, Advise, Guide	Advising/Moderating Tools

Figure 1: Forms of Collaboration Management [10]

These indicators can be displayed to the group members without further information, in which case it is left to the group (or a moderator/tutor/teacher in the loop) to pick up on them or not. Or additional information can be provided along with displaying the indicator, such as referring to an ideal model of interaction. Again, it is up to group if it elaborates on this or simply goes on with its task. Alternatively, the management system itself can kick in and provide *advise* to the group as a whole or to individual members.

In short, three types of tools can be used to support collaboration management: Mirroring, metacognitive and advise tools (cf. Figure 1). An example for a management system that performs very few transformations on the data collected is SimPLE [18]. Records are kept of the learners manipulations of a computer simulation and are displayed in graphical format below the simulation interface. These histories can be shared with other learners. Jermann [19] provides an example for an approach where not only the interaction with a simulation is traced, but in addition data on the interaction of (two) learners are

displayed in form of dynamic graphs. In situations where a number of people interact, bar charts and the like can quickly become hard to discern. In this case, social networks and similar techniques can be employed to display interaction behaviour. These methods, originally developed to help researchers analyze social interaction in large communities such as newsgroups etc. [e.g., 20, 21], can also be used to provide information for groups who are 'live' on-line.

An example for an approach that not only traces and displays the quantitative aspects of interaction, but tries to identify the meaning of such interactions is *action-based collaboration analysis* [22]. Muehlenbrock [23] developed within this framework an *activity recognition* approach where actions are conceptualized as occurring in the context of some state (situation) and in the context of other actions. Taking a stream of action messages from the shared workspace and a set of operators as an input, activity recognition automatically and incrementally infers abstract notions of group activity and interpretations of problem-related conflicts and coordinations. Recognized activities are fed back as an input to the recognition mechanism to derive even higher concepts, progressing for instance from identifying a 'insert and delete' action to a potential 'conflict' between two collaborators.

It is a logical step to go from identifying such patterns to comparing them with normative models of interactions and to offer advice or guidance when discrepancies between the descriptive and the prescriptive side occur. Barros and Verdejo [11] in their DEGREE system do not analyse in great deal the semantics of students' contribution to an (asynchronous) forum, but force students to classify each contribution in terms of certain categories (contribution types) and provide advice to contributors based both on quantitative as well as qualitative indicators. One of the most advanced advice systems is COLER [24]. Based on tracking actions in a graphical collaboration environment (i.e., action-based as pioneered by Muehlenbrock and Hoppe, this time the actions correspond to entity-relationship modelling for data base design as the learning domain), COLER computes advice suggestions much in the spirit of a 'classical' ITS coach module and provides hints and guidance on a number of collaboration parameters relating to discussion, participation, self-reflection, and general characteristics of good entity relationship modelling practice.

Clearly, as we step down in Figure 1, the approaches to collaboration management become more advanced. This does not mean, however, that we should feel forced to aim at the highest level of technical sophistication automatically. A number of questions can be raised to come to more systematic decisions. An obvious one is the cost-benefit ratio: Do learning teams really perform significantly better when being advised as compared to just being informed about their performance? Or is it sufficient to just add mirroring information? Do groups pick up this sort of meta-cognitive information when it is presented to them without further turning it into advice? Another issue is that of agency: Will groups' learning opportunities be substantially reduced if a guidance system takes over some of the functions a group normally has to realize by itself? And we have to deal with the question just where the prescriptive models for groups interaction and problem solving activities do come from.

One possible – and elegant - answer to the last question is given by Soller, Wiebe, and Lesgold [25]. They use machine learning techniques to identify patterns that distinguish successful from less successful groups (the success criterion in this case being the amount of knowledge sharing that was observable among group members). Their answer, then, is empirical: Prescriptions can be based on observations of groups behaviour. While this approach has its merits, it has limitations as well. As with all inductive techniques, the models identified are dependent on sampling and size of the learning set; there's always the possibility that groups not observed yet would, if accounted for, lead to

substantial changes in the model. Besides this principle problem, there's the problem of what counts as success (i.e., the criterion) and what aspects of the group behaviour are recorded and fed into the induction algorithm. Both kinds of decisions will affect the outcome of the machine learning exercise quite a bit.

In a number of studies we have conducted in the last two years, we address some of the issues just raised. In particular, we looked into just how effective more or less simple tracing and mirroring methods are in order to support groups' collaboration management. In addition, we tried to identify aspects of "optimal" group performance, based on research in social psychology.

2. Towards a Prescriptive Model of Collaboration: Psychological Aspects of Groups

If we look from a psychological perspective onto the suggestions put forward in the fields of CSCW and CSCL as to how to support groups in their problem solving and learning, it becomes obvious that research in both areas is often based on an over-simplified understanding of what groups and teams are about. In particular, groups are frequently seen as being mainly engaged in problem solving tasks, in getting their task done. Although it is acknowledged that interaction in groups are sometimes not about the task, these exchanges are classified as 'off-task' that should be reduced as much as possible.

2.1 Social Dilemma Research

Important insights on the nature of groups can be gleaned from research on social dilemmas. This line of research reminds us of the fact that 'collaboration' is often problematic for humans: "At the root of the problem of cooperation is the fact that there is often a tension between individual and collective rationality. This is to say that in many situations, behaviour that is reasonable and justifiable for the individual leads to a poorer outcome for all" [26]. This is even the case for the simplest possible case of a social dilemma, involving two people faced with the decision of whether to cooperate or behave selfishly. Both can gain by cooperating, but there is a temptation to be selfish. If both people behave selfishly, however, they are both worse off than they might have been otherwise. Studying such simple, yet prototypical situations, Axelrod [27] came to the conclusion that three conditions need be met for even the possibility of cooperation: (1) it must be likely that two individuals will meet again in the future; (2) the individuals must be able to identify each other; (3) individuals must have information about how the other person has behaved in the past. Godwin [28] makes a similar point when stressing the importance of promoting continuity in online groups and when suggesting that online communities should provide for institutional memory – durable records of the events and history of the group. Important contributions also come from Ostrom [29] who found among other things that in successful communities most of the people affected by the communities' rules were able to participate in modifying them. She also found that even the most successful community requires a system to monitor and sanction members' behaviour, but that this works best when the monitoring is carried out by the members themselves rather than an external authority.

For the case of CSCL, a number of lessons can be drawn from social dilemma research. For one, you can try as hard as you want, it is highly unlikely that any group support tool will have much effects as long as Axelrod's minimal conditions are met; in particular not in situations where 'virtual' learning groups where members are brought together on suggestion of a learning management system because they work at the same assignment. Such 'groups' may be more 'virtual' than we like them to be. A second

message is that tracing and mirroring can, if nothing else, provide for the kind of group memory that is identified by many dilemma researches as important. Finally, advise systems which are seen as an authority external to the group may have positive effects in the short term but – if Ostrom is right – may not be as successful as they could be in the long run.

2.2 Small Group Research

When sociologists and psychologists speak of ‘successful’ groups, they mean not necessarily only those that perform best on whatever task, but also those that manage to keep their interaction going over some time period. Looking at the dropout rate of distance education in general and net-based courses in particular, this is not a small accomplishment. They manage to do so not only because they get their tasks done, but also because they take care of the group and its members. However, with respect to technology-mediated groups, comparatively little attention has been devoted to study how groups accomplish this – and how they can be supported: “Research on technology and groups to date has focused almost exclusively on the production functions of those groups. Relatively little attention has been paid to how, and how well, those groups socialize, train, and support their members, and to how, and how well, those groups take care of their own system of maintenance” [30].

To mention at least one theory with roots both in group research and organisational psychology, we focus on a general framework called *time, interaction, and performance* (TIP) developed by Joseph McGrath [9]. TIP theory regards groups as continuously and simultaneously engaged in three major functions: production – getting the tasks done; member support – contributions of the group to its participating members; and group well-being – “contributions of the group to its own continued functioning as an intact social unit” [30]. In addition to stressing that groups are engaged in multiple functions, TIP theory also takes into account the fact that groups go through different phases – or *modes* as they are called in TIP – when working on a task. Four modes are distinguished: Inception of a project (goal choice), solution of technical issues (means choice), resolution of conflict, and execution of the performance requirements of the project. McGrath speaks of ‘modes’ rather than ‘phases’ because these modes are not occurring in a strict sequence; groups may be oscillating between these modes. The modes are related to, but do not exhaust *temporal* aspects of groups. Important issues in this respect are processes of coordination and synchronisation amongst group members and amongst the group and its (organisational and social) environment. Also, issues of change in membership and the question of how newcomers are integrated into teams belong to the temporal dimension. Finally – and this is a contribution of McGrath which has been well received in the CSCW community – TIP theory includes the *task* dimension, paying respect to the fact that group interaction and performance is greatly affected by the type and difficulty of the tasks the group is performing. The task classification schema suggested in [31] distinguishes between four performance categories: to generate ideas or plans, to choose a correct answer or a preferred solution, to negotiate conflicting views or interests, and to execute, possibly in competition with opponents or against external standards.

Again, a number of valuable lessons for those like us who want to support learning in groups (and learning groups) come from this kind of research: Do take into account the nature of the (learning) task – a lesson that seems to have slipped out of the CSCL research picture. Keep in mind that groups are not static, but are developing over time (members become more knowledgeable, the group interaction patterns change, members leave the group, new ones join the group). And cater to the fact that groups are working in multiple functions and modes. Management of groups’ collaboration will need to be more than

management of the interaction around the learning task, it will need to take into account the other aspects of interaction and coordination as well.

3. Empirical Studies on Tracking and Mirroring

Our own work is influenced by TIP theory in particular. Important characteristics of our approach include the the extraction of data from collaboration and the provision of abstracted views (indicators) as a substitute for missing communication and organization cues. In particular, we investigated how interaction and problem-solving feedback can support the interaction and performance of students in small problem-based learning groups that cooperate via Internet technologies in a highly self-organised fashion. Since the possibility of tracking and maintaining processes of participation and interaction is one of the advantages of online collaboration, ephemeral events can be turned into histories of potential use for groups.

We chose two ways to analyze how such group histories can be used for learning purposes. Firstly, parameters of interaction such as participation behaviour, learners' motivation, and problem solving capabilities were recorded and fed back in a computationally aggregated manner. This acts as an additional information resource for the group. This data could thus be used to structure and plan group coordination and to enhance group well-being (*well-being function*). Secondly, we tracked group members' problem solving behaviour during design tasks and provided feedback by means of problem-solving protocols. These protocols can be used to enhance a group's problem solving process in further tasks (*production function*). In order to establish these functions, we developed a collaboration platform integrating interaction and problem-solving feedback.

Both for pedagogical reasons and to make it easier to trace interactions without having to analyze natural language, we use construction or design tasks in our studies. Learning-By-Design [32, 33] requires that a problem always be linked to creation of an artefact (design product). This kind of learning requires students to externalize their knowledge, discuss different possible solutions and provide arguments for a single design product, all of which are effective learning mechanisms. Not only do students have to discuss different aspects of and solutions to a problem, they also have to develop an artefact (such as a plan, a design document) that assembles representations of the original problem and possible solutions. To instantiate this methodology, we developed a number of more or less authentic problems in the area of instructional design [34]. Two studies, one focussing on asynchronous, the other on synchronous communication, are reported next.

3.1 Study 1: Asynchronous Document Exchange

Figure 2 shows the collaboration platform developed for a distributed university course that was taught in a 'blended' fashion, requiring face-to-face as well as on-line participation [34]. The communication facility is based on a Lotus Notes platform, merging tools for document management with automatic display possibilities for interaction parameters and problem-solving protocols. During collaboration each group member had to fill in a form stating his or her motivation in regular intervals. This data was aggregated over time and visualized in a line graph, showing all group members' motivation (one curve for each learner; see Figure 2 top right). The contribution behaviour of each learner was recorded by the system itself and, in relation to all other group members' contributions, quantitatively represented as a pie chart (Figure 2 lower right part). Both of these feedback mechanisms (the "interaction history" of a group) can help to identify problems in motivation as well as

participation. This provides a diagnostic means by which to give member-support and thus, help to maintain the well-being of the group members.

Another type of support is given by means of aggregated problem-solving protocols that contain groups' essential steps of solving previous design problems and link them to a normative model of instructional design. These meta documents ("design histories") are produced manually by a tutor or instructor and provide an insight into the problem solving process of a group by showing them milestones of their previous work. By means of such feedback, learners are able to identify strengths as well as weaknesses in their production function and can easily re-use existing solutions and modify them for further problems.

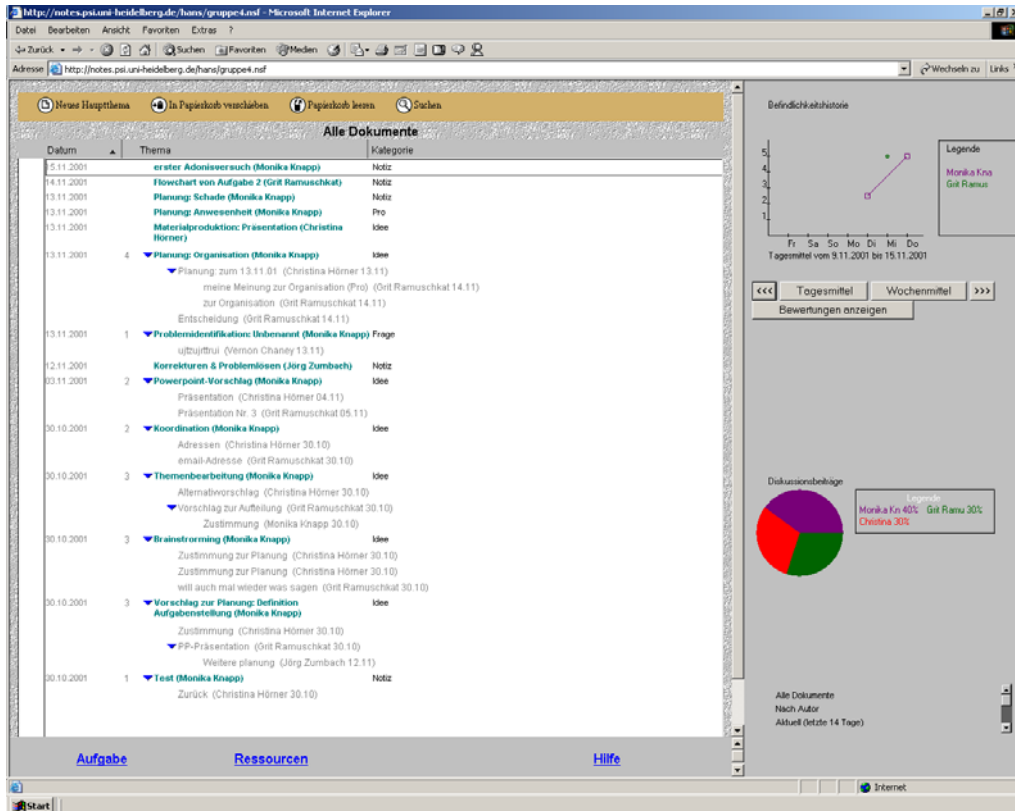


Figure 2: Notes database with additional collaboration information

In a course lasting over 4 months we evaluated our methodology concerning group-well being and production function. In a controlled experiment we examined the influence of our feedback techniques on groups from three to five members – a total of 33 participants. These groups participated in a problem-based course about Instructional Design that was a combination of Problem Based Learning (PBL) and Learning-By-Design. Learners were required to design several online modules for a fictitious company. Tasks were presented as problems including a cover story. Each problem had to be solved over a period of two weeks (i.e., an Instructional Design solution including sample lesson blueprints had to be presented). All materials were accessible online and, additionally, tutors were available during the whole course to support the students. At the end of each task, the groups presented their results to other groups.

The groups were randomly assigned to one of four treatment conditions: interaction history only, design-history only, with both histories and without any feedback histories, i.e., a 2x2 design with the factors interaction history and design history used. We employed several quantitative and qualitative measures before, during and after the experimental

phase in order to assess motivation, interaction, problem solving, and learning effects. Our measures included the student curriculum satisfaction inventory [35] and an adapted version of the critical thinking scale [36].

We attempted to answer one major question: how far does the provision of feedback in the form of design and interaction histories, as well as their different combinations, have an influence on students' learning? Generally, we assumed that groups with any form of histories would perform better than those without, especially regarding the motivational and emotional aspects supporting the well-being function and the production aspects supporting the production function of a group.

In terms of the outcomes in favour of the application of feedback within group processes, the results are encouraging. Groups provided with design history feedback had significantly better results in knowledge tests, created qualitatively better problem solutions, produced more contributions to the task, and expressed a higher degree of reflection concerning the groups' organization and coordination (Figure 3). At the same time, the presence of interaction histories influenced group members' emotional attitudes towards the curriculum and enhanced their motivation for the task.

Based on our data, it seems reasonable to conclude that the different kinds of feedback positively influence different aspects of group behaviour. Feedback in form of interaction histories seems to have an effect on the group's well-being function, whereas feedback in form of design histories seems to influence a group's production function according to McGrath's (1991) conception of group functions.

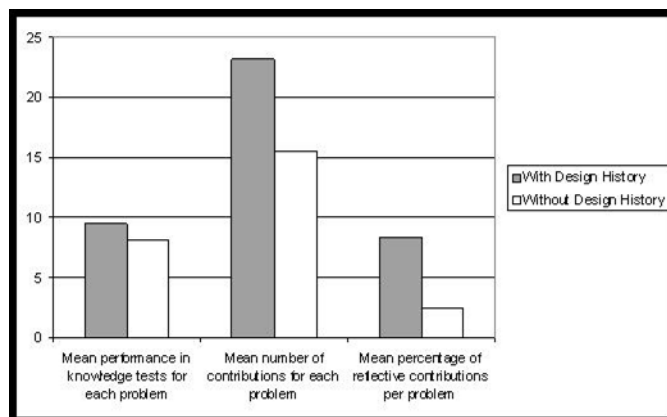


Figure 3: Outcomes in cognitive parameters

3.2 Study 2: Synchronous and Activity-Based

In this study [37] we cooperated with the Collide group at the University of Duisburg and used their JavaMatchMaker server [38] to develop a specific synchronous collaboration tool. JavaMatchMaker is a very flexible system by providing dynamic and partial synchronization of user interfaces. It is possible to start and stop the synchronization at any point of the application's lifetime and to synchronize each component of an application's interface individually with a component of another application's interface, thus allowing the synchronization of applications with completely different interfaces. The MatchMaker server is a core component of open distributed learning environments [39] that are characterized by the provision of opportunities for group interaction, the combination of intelligent support with interactive learning environments, and a distributed component-based architecture.

The application EasyDiscussing (Figure 4) is based on JavaMatchMaker and has been developed for this study. Its main component is a shared workspace with a set of typed cards that can be dragged from a palette below the workspace and dropped at an arbitrary position within the workspace. In this application, cards are text cards or are annotation cards according to the IBIS notation [40] and they can be linked by means of directed edges. Further components of the application are an overview panel providing a bird's eye view on the workspace, a chat interface with typed contributions corresponding to the annotation cards, and a feedback component, which visualizes quantitative measures such as the number of each user's contributions in the chat and the shared workspace.

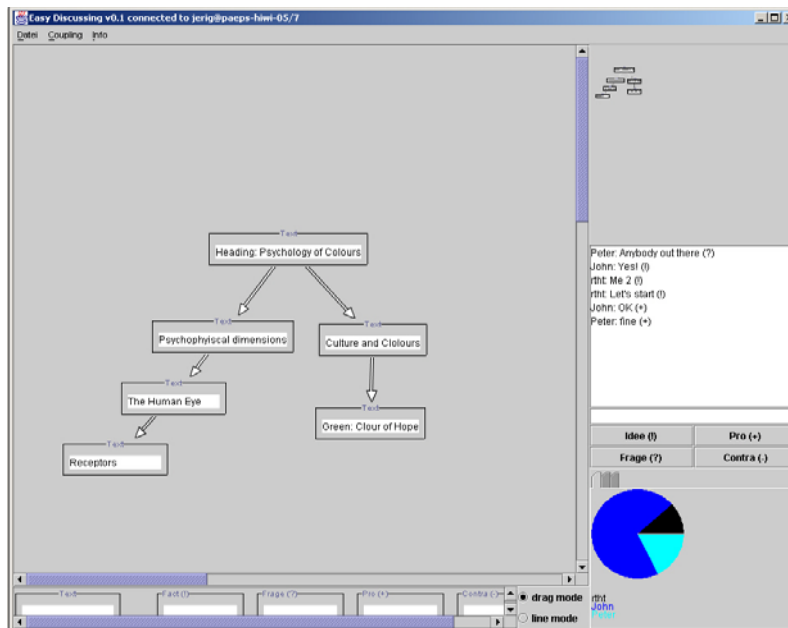


Figure 4: EasyDiscussing Interface

For the control condition, the chat interface and the feedback component can be switched off. In addition, the feedback component also includes visual representations of qualitative aspects such as an interpretation of constructive and destructive effects of user actions as described in [22]. These have not yet been used in the empirical investigation. Furthermore, all user actions are logged to a file in a XML-based format.

This study was designed to examine parameters influencing group processes during a co-constructive learning task using the shared workspace environment as described above. The main idea of the study is the investigation of how groups can be influenced by feedback of their own socio-emotional parameters and what kind of interaction patterns take place during a co-constructive design task. We use here a combined top-down/bottom up analysis: On the one hand, we collect data by using traditional psychometric methods. On the other hand, the collaboration platform itself allows a detailed tracking of user behavior and a semantic analysis of interaction patterns during collaboration. We wanted to examine the effects of the combination of collecting data about collaborative behavior and socio-emotional data in real time as well as its re-use as direct feedback for supporting small group interaction. Beyond the specific experiment, there is also a methodological interest in exploring the potential of combining different techniques of tracking and analysis.

Learners have to develop an online screen version of a linear text. Basically this task requires to chunk the linear text into coherent parts, add or delete parts, provide adequate headings and develop a navigation structure.

Subjects were randomly assigned to small groups of three members each. Nine subjects (= three groups) participated in an experimental condition with the tracking of interaction as well as motivational and emotional parameters directly displayed as feedback to each whole group. The other nine (also three groups) subjects in the control condition did not get any automatic feedback about interaction, motivational and emotional parameters. The task for all groups was the same: To collaboratively re-design a linear text into a didactically structured online-text. This design task had to be fulfilled by using the EasyDiscussing tool. In order to provide further information a hypertextual information base for didactical screen design was available online. All subjects had to perform a multiple-choice pre- and a post-test assessing knowledge about didactical screen design.

As collaboration platform for the study the application EasyDiscussing as described above has been used. While the experimental group (EG) could use the full functionality of EasyDiscussing, the control group (CG) had the same interface but without the feedback component and chat interface. In the CG, only annotation cards which had to be erased after their use were available for discussing decisions. Parallel to their collaboration task subjects emotions and motivation have been surveyed. In intervals of 30 to 40 minutes they were asked to fill in a 5-point Likert-scale in reaction to the question “How do you feel?” and “To which degree are you motivated to work on this task?”. The values of each entry and each subject were displayed to experimental group members using a dynamic graph. These graphs were not shown to the control group. Figure 5 shows a typical diagram. In order to assess subjects knowledge concerning the task we developed a multiple choice test with 16 items that was used as a pre- and post-test.

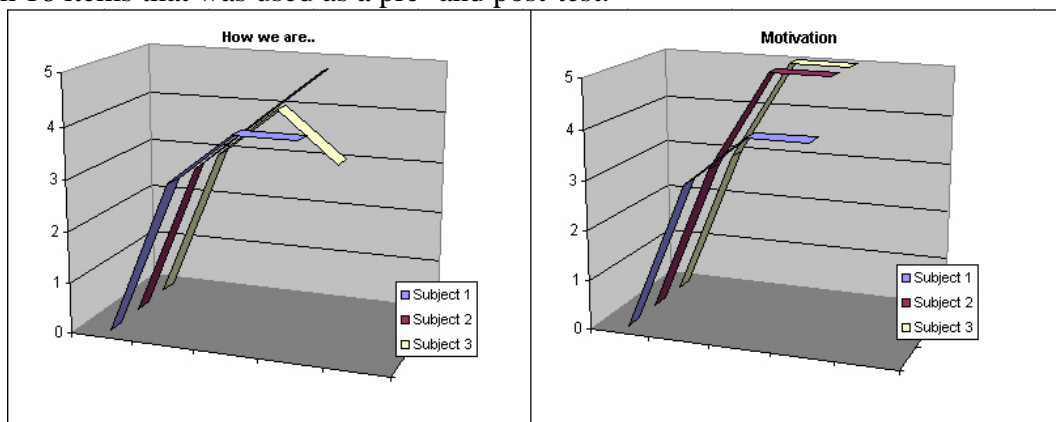


Figure 5: Graphical display of motivation and emotion over time

We expected influences of the feedback we provided for the experimental groups in this experiment. In particular, we expected that providing dynamic feedback on the members participation behaviour should lead to an increased and equally distributed participation. Furthermore we expected that the feedback of emotional and motivational parameters should influence how intensively the groups reflected on its well-being and on problems specific members might have.

The results of subjects' performance in the pre-test concerning domain knowledge revealed no significant differences. There were also no difference between both groups in post-test performance. Both groups mastered the post-test significantly better than the pre-

test. Interaction between both tests and groups was not significant ($F(1, 16) = 0,19, p = 0,67$; see Figure 6)

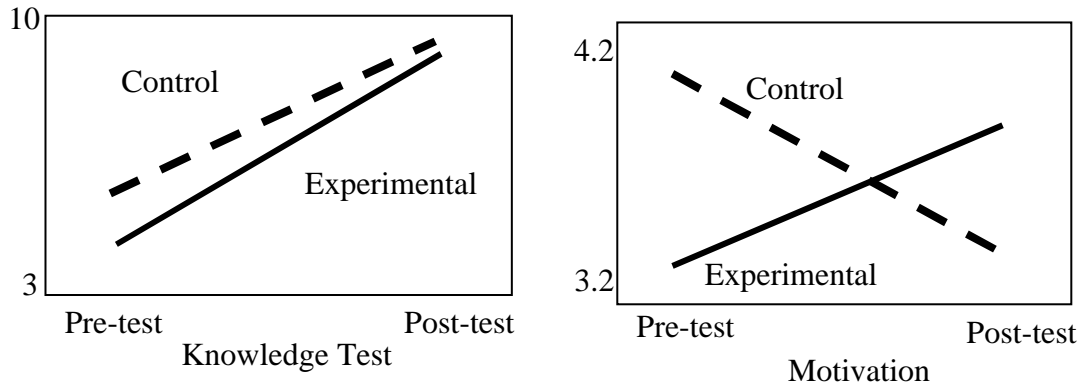


Figure 6: Effects on Knowledge and Motivation

We found no significant differences between both groups in pre-test and post-test regarding the emotional state. There was not pre-post effect as well as no significant interaction between repeated measurement and experimental condition ($F(1, 16) = 0,8, p = 0,78$). The groups also showed no differences in pre- and post-test regarding the motivational parameter. There were also no differences between pre- and post-test. The interaction of repeated measurement became significant (see Figure 6).

For analysis of group communication patterns an overall value of all objects (“cards”) created in EasyDiscussing was computed and compared. This includes in the EG all postings in the chat-window and the shared workspace, in CG all nodes created in the shared workspace. An ANOVA revealed no significant difference between overall number of postings in both conditions. A more detailed view on subjects’ discussion structures showed a more frequent use of *pro* and *contra* postings in the experimental group. There were no significant differences in use of *idea* and *question* postings. The analysis of subjects’ distribution of contribution behaviour was computed by subtracting each individual’s number of postings from the corresponding group mean. Subjects in EG showed a more equally distributed contribution behaviour than those in CG although the difference became not significant.

4. Conclusions

Comparing Study 1 and 2, we can conclude that mirroring group interaction has relatively small effects when applied in *ad-hoc* groups that work together for only short amount of time and will not meet again in this combination. This supports Axelrod’s point [27] that minimal conditions must be met before an assembly of people starts to see each other as a group or community and begins to cooperate. Time was also an important factor in Study 1. In an analysis not reported here (but see [34]) we found that the effects of mirroring decreased over time: it was particularly helpful for groups in their first encounters (2-4 weeks) and became less so in their continuing work. It seems most plausible to assume that monitoring and mirroring information is most helpful in the “storming and norming” phase of a group’s development and becomes less important once this phase is over (provided there are no changes in group membership).

Returning to the taxonomy for collaboration management tools depicted in Figure 1 and the question we raised on how to come to a rational decision which kind of tool to

employ, we can conclude that tracing and mirroring is effective (for groups that work/learn together for some time) when compared to the “no further support” condition. Our studies do not allow to answer the question if significant gains can be established by introducing additional measures, in particular those of the advise type. Further research is needed to look into this issue.

References

1. Slavin, R.E., *Cooperative Learning*. 2nd ed. 1995, Boston: Allyn and Bacon.
2. Cohen, E.G., *Restructuring the classroom: Conditions for productive small groups*. Review of Educational Research, 1994. **64**(1): p. 1-35.
3. Dillenbourg, P., Baker, M., Blaye, A. & O'Malley, C., *The Evolution of Research on Collaborative Learning.*, in *In P. Reimann & H. Spada (Eds.), Learning in Humans and Machines: Towards an interdisciplinary learning science (pp. 189-211)*. London: Elsevier. 1995. p. 189-211.
4. Stahl, G., ed. *Computer Support for collaborative learning: Foundations for a CSCL community. Proceedings of CSCL 2002*. 2002: Boulder, CI.
5. Björck, U. *Distributed problem-based learning in social economy - a study of the use of a structured method for education*. in *Annual Meeting of the American Educational Research Association*. 2001. Seattle.
6. Cameron, T., Barrows, H. S. & Crooks, S. M., *Distributed Problem-Based Learning at Southern Illinois University School of Medicine.*, in *In C. Hoadley & J. Roschelle (Eds.). Computer Support for Collaborative Learning. Designing New Media for a New Millenium: Collaborative Technology for Learning, Education, and Training (pp. 86-94)*. Palo Alto: Stanford University. 1999.
7. Milter, R.G.S., J. E., *Using Lotus Notes to Faciliate Action Learning*. 1999. p. <http://mbawb.cob.ohiou.edu/paper1.html>.
8. Steinkuehler, C.A., et al., *The STEP environment for distributed problem-based learning on the world wide web*, in *Computer support for collabroative learning: foundations for a CSCL community*, G. Stahl, Editor. 2002, Erlbaum: Hillsdale.
9. McGrath, J.E., *Time, Interaction, AND Performance (TIP). A Theory of Groups.*, in *Small Group Research*. 1991. p. 147-174.
10. Jermann, P., A. Soller, and M. Muehlenbrock, *From mirroring to guiding: a review of the state of the art technology for supporting collaborative learning*, in *European Perspectives on computer-supported learning*, P. Dillenbourg, a. Eurelings, and K. Hakkarainen, Editors. 2001, University of Maastricht: Maastricht, NL. p. 324-331.
11. Barros, B. and F. Verdejo, *Analysing student interaction processes in order to improve collaboration. The DEGREE approach*. International Journal of Artificial Intelligence in Education, 2000. **11**.
12. Daft, R.L. and R.H. Lengel, *Information richness: A new approach to managerial behavior and organizational design*. Research in Organisational Behavior, 1984. **6**: p. 191-233.
13. Dennis, A.R. and J.S. Valacich. *Rethinking media richness: Towards a theory of media synchronicity*. in *32nd Hawaii International Conference on System Sciences*. 1999. Hawaii.
14. Suthers, D.D., *Towards a systematic study of representational guidance for collaborative learning discourse*. Journal of Universal Computer Science, 2001. **7**(3): p. 1-23.
15. Stenning, K. and J. Oberlander, *A cognitive theory of graphical and linguistic reasoning: Logic and implementation*. Cognitive Science, 1995. **19**(1): p. 97-140.

16. Larkin, J.H. and H.A. Simon, *Why a diagram is (sometimes) worth ten thousand words*. *Cognitive Science*, 1987. **11**(1): p. 65-100.
17. Anderson, A., et al., *Computer support for peer-based methodology tutorials*. *Journal of Computer Assisted Learning*, 2000. **16**(1): p. 41-53.
18. Plaisant, C., et al., *The design of history mechanisms and their use in collaborative educational simulations*, in *Proceedings of the Computer Support for Collaborative Learning (CSCL) 1999 Conference*. 1999, Stanford University: Palo Alto, CA. p. 348-359.
19. Jermann, P., *Task and interaction regulation in controlling a traffic simulation*, in *Computer support for collaborative learning: foundations for a CSCL community*, G. Stahl, Editor. 2002, Erlbaum: Hillsdale. p. 601-602.
20. Wortham, D.W., *Nodal and matrix analyses of communication patterns in small groups*, in *Proceedings of the Computer Support for Collaborative Learning (CSCL) 1999 Conference*. 1999, Stanford University: Palo Alto, CA. p. 681-686.
21. Reffay, C. and T. Chanier, *Social network analysis used for modelling collaboration in distance learning groups*. 2002.
22. Muehlenbrock, M. and H.U. Hoppe, *Computer-supported interaction analysis of group problem solving*, in *Proceedings of the conference on computer-supported collaborative learning, CSCL-99*, C. Hoadley and J. Roschelle, Editors. 1999, Erlbaum: Mahwah. p. 398-405.
23. Muehlenbrock, M., *Action-based collaboration analysis for group learning*. 2001, Amsterdam: IOS Press.
24. Constantino-Gonzalez, M., D.D. Suthers, and J.G. Escamilla de los Santos, *Coaching web-based collaborative learning based on problem solution differences and participation*. *International Journal of Artificial Intelligence in Education*, in press. **13**.
25. Soller, A., J. Wiebe, and A. Lesgold. *A machine learning approach to assessing knowledge sharing during collaborative learning activities*. in *CSCL 2002 Conference*. 2002.
26. Kollock, P. and M. Smith, *Managing the virtual commons: Cooperation and conflict in computer communities*, in *Computer-mediated communication: Linguistic, social, and cross-cultural perspectives*, S. Herring, Editor. 1996, John Benjamins: Amsterdam. p. 109-128.
27. Axelrod, R., *The evolution of cooperation*. 1984, New York: Basic Books.
28. Godwin, M., *Nine principles for making virtual communities work*. *Wired*, 1994. **2**(June): p. 72-73.
29. Ostrom, E., *Governing the Commons: The evolution of institutions for collective action*. 1990, New York: Cambridge University Press.
30. McGrath, J.E. and A.B. Hollingshead, *Groups interacting with technology*. 1994, London: Sage.
31. McGrath, J.E., *Groups: Interaction and performance*. 1984, Englewood Cliffs, NJ: Prentice-Hall.
32. Fischer, G., R. McCall, and A. Morch, *Design environments for constructive and argumentative design, human factors in computing systems*, in *CHI'89 Conference Proceedings*. 1989, ACM: New York. p. 269-275.
33. Kolodner, J.L., *Educational implications of analogy*. *American Psychologist*, 1997. **52**(1): p. 57-66.
34. Zumbach, J. and P. Reimann, *Influence of feedback on distributed problem based learning*, in *Designing for Change in Networked Learning Environments*, B. Wasson, S. Ludvigsen, and U. Hoppe, Editors. 2003, Kluwer: Dordrecht. p. 219-228.

35. Dods, R.F., *An action research study of the effectiveness of problem-based learning in promoting the acquisition and retention of knowledge.*, in *Journal for the Education of the Gifted*. 1997. p. 423-437.
36. Newman, D.R., et al., *Evaluating the quality of learning in computer supported cooperative learning*. *Journal of the American Society for Information Science*, 1997. **48**(6): p. 484-495.
37. Zumbach, J., et al. *Multi-dimensional tracking in virtual learning teams: An exploratory study*. in *CSCCL 2002 Conference*. 2002.
38. Tewissen, F., et al. "*MatchMaker*": *synchronising objects in replicated software-architectures*. in *6th International Workshop on Groupware, CRIWG-2000*. 2000. Madeira: IEEE CS Press.
39. Muehlenbrock, M., F. Tewissen, and H.U. Hoppe, *A framework system for intelligent support in open distributed learning environments*. *International Journal of Artificial Intelligence in Education*, 1998. **9**: p. 256-274.
40. Conklin, E.J., *Capturing organizational memory*, in *Groupware and computer-supported cooperative work*, R.M. Baecker, Editor. 1993, Morgan Kaufman: San Francisco. p. 561-565.