CO-CONSTRUCTING ARTEFACTS AND KNOWLEDGE IN NET-BASED TEAMS: IMPLICATIONS FOR THE DESIGN OF COLLABORATIVE LEARNING ENVIRONMENTS

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Computer-based learning environments for science and mathematics education support predominantly individual learning; from first generation drill and practice programs to today's advanced, knowledge-based tutorial systems, one learner interacting with one computer has been the typical setting. Mathematics educators, however, increasingly appreciate the value of collaborative learning and include team-learning activities in their lessons. In this presentation, drawing on our research in science and design areas, an overview is provided of the approaches and lessons learned regarding computer-supported collaborative learning and a number of design guidelines for computer-supported collaborative learning environments are suggested. Since equations and graphs are so important in mathematics, particular attention is paid to the role of external representations (and their co-construction) for computer-mediated collaboration.

APPROCHES TO FOSTER COLLABORATIVE LEARNING

Why foster collaboration? There are two arguments for supporting individuals as well as groups in cooperative behavior. First, cooperative behavior and, thus, collaborative learning leads to better performance of students compared to individual or competitive learning (Barron & Sears, 2002; Johnson & Johnson, 2004). Second, individuals in a group do not automatically cooperate and act as a group. A huge amount of contributions is dedicated to enhance collaborative learning in computer-mediated and residential cooperative learning. Johnson and Johnson (2004) distinguish four different basic types of cooperative learning: formal cooperative learning, informal cooperative learning, cooperative base groups and academic controversy. Mostly, formal and informal cooperative learning are addressed by methods fostering collaborative behavior. In some cases, the different types of cooperative learning represent several steps in the progress of a group (e.g., a group starts with informal cooperative learning, establishes formal cooperative learning afterwards and, finally, builds a cooperative base group). While informal cooperative learning according to the definition of Johnson and Johnson (2004) is restricted to short time intervals, most programs and assistance focus on the enhancement of formal cooperative learning.

Numerous methods of assisting learners in small group formal cooperative learning have been proposed. Some approaches are on the level of instructional design demanding specific cooperation patterns such as Group Jigsaw, Reciprocal Teaching

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or Problem-Based Learning. Other approaches are direct teaching of cooperative behavior, modeling, or scripting (e.g. Rummell et al., 2002). Especially for groups that are beginning a "collaborative episode" (i.e., there are no or little experiences in cooperative learning and the building of social relationships is at its beginning) such direct intervention is appropriated in order to avoid frustration and to reduce cognitive load. Even more experienced learners may benefit form assistance in cooperation: Especially in groups with many degrees of freedom related to cooperation and task fulfillment little or poor interaction is reported (e.g. Cohen, 1994).

The problem of poor peer interaction is well known in residential collaborative learning, but 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 or grounding. But also and in particular social mechanisms like building positive interrelationships, establishing a group identity etc. are afflicted. Major causes for these difficulties derive from a lack of external cues as described in models of cues-filtered out and canal reduction.

Recent research in CMC-based (computer-mediated communication) collaborative learning has contributed a variety of technological/instructional approaches and solutions to overcome these problems. Especially scripting of collaboration (as a scaffolding mechanism) has gained attention in order to enhance turn-taking (Pfister & Mühlpfordt, 2002; Reiserer, Ertl & Mandl, 2002), design rationale (Buckingham-Shum, 1997) or 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 to guide learners in the sense of an optimized behavioral model (e.g. problem solving heuristics) or a coordinated exchange between several learners. Furthermore, 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, when structuring interaction and discourse for learners, we always run the risk of interrupting spontaneous discourse. Scripting implies external guidance on sequence or categorization of contributions, but it is very difficult to identify discourse and patterns that are generally appropriate and effective.

In our recent research, we tried to avoid such a drastic and direct intervention that limits learner control by providing an inflexible structure. Instead of pre-structuring, we pursue what we call a "post-hoc structuring", i.e., we take the data derived form interactions (and additional variables assessed from learners) and re-use them for scaffolding. This way we avoid direct interference with the communication process, provide authentic material (based on learners' own contributions) and, hopefully, help students to become more self-efficient. Furthermore, this approach provides learners with accurate information about their current status within a group and group's progress and also with information on possible further directions that can optimize group functions (e.g., communication, group-members' interrelationships and learning or problem-solving outcomes). Before we have a closer look at our methods of collaboration management, a study is presented that analyses a discourse structuring approach.

SCAFFOLDING

In this study, we[9] analysed a scaffolding approach that is typical for what Reiser (2002) coined "providing structure". In this case, structure is provided on how student can communicate with each other. In particular, we looked at three levels of structuring (electronic) communication: Unstructured – a chat tool was provided to groups of (three) students; Simple-Structure: A graphical argumentation schema was provided on a shared whiteboard with four types of "nodes" (claim, pro- and contra-argument, sub-claim; Full-Structure: in this condition, seven node types had to be used (question, pro-and contra argument, idea, decision, fact, and miscellaneous, see Fig. 1) following the IBIS notational conventions (see Buckingham-Shum, 1996).

We ran an experiment with three conditions (Chat, Simple-Structure, Full-Structure) and 5 groups of 3 participants in each condition. Participants had to develop collaboratively an argument for a "wicked" environmental issue, the benefits and risks of transporting oil on sea with tankers. Our expectation was that the higher the degree of argument structure, the better the quality of the arguments a group will produce. In order to evaluate the quality of the arguments, we used the coding scheme of Newman and colleagues (Newman, Johnson, Webb & Cochrane, 1997) that has been developed to assess the quality of arguments exchanged in computer-mediated communication. This method yields a "critical thinking index" which varies between 0.0 and 1.0, with values close to 1.0 indicating higher argument quality.

Argument quality did indeed increase as a function of scaffolding through argument structuring, with a significant differences between all three conditions. It is worth noting, however, that increasing the structure led to a decrease in the frequency of arguments.

[9] Oliver Orth helped with the experimentation and data analysis.

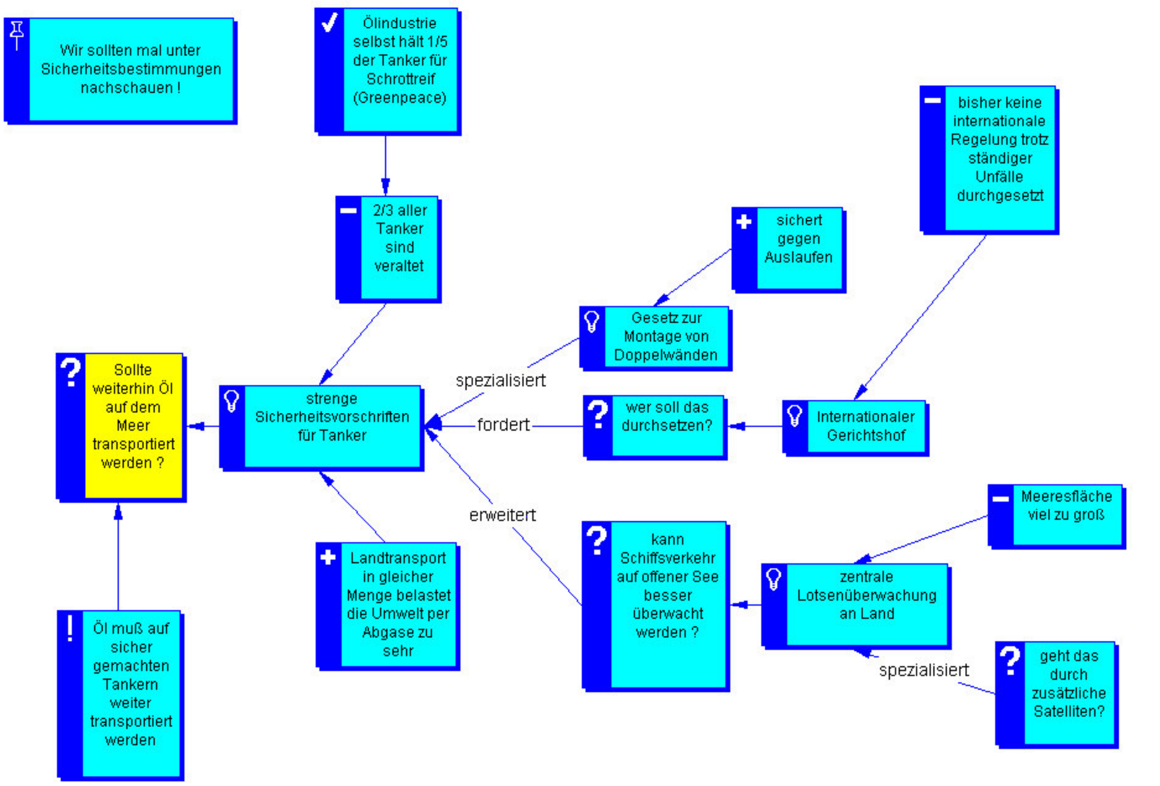

Figure 1: Argument graph using the full-structure (IBIS) notation

FEEDBACK AND GUIDANCE

Substantial research has been dedicated to find support mechanisms for online collaborators. Many authors discuss possibilities of scaffolding by structuring computer-mediated communication (e.g. Dobson & McCracken, 1997; Jonassen & Remidez, 2002; Reiser, 2002). Common to all these approaches is the provision of a structure for discourse and/or problem-solving. Instead of pre-structuring we pursue a way of post-hoc structuring interaction in online learning groups.

CMC itself provides the basis for this approach. During computer-mediated communication, all data can easily be stored and re-used for feedback purposes. In addition, software interfaces designed for CSCL (computer-supported collaborative learning) allow collecting individual quantitative data that can be used for further calculations in real time. Both data sources combined can easily be used to analyze individuals' as well as groups' performance automatically. In this way online learning groups provide the basis for feedback on their process without further interventions.

For instance, Barros and Verdejo (2000) describe an approach to provide feedback of group characteristics and individual behavior during computer-supported collaborative work based on a set of attributes that are computed out of data derived from learners' interactions. Their automatic feedback gives a qualitative description of a mediated group activity concerning three perspectives: a group's performance in reference to other groups, each member in reference to other members of the group, and the group by itself. Their approach allows extracting relevant information from online collaboration at different levels of abstraction. Although this approach seems to be very advantageous for enhancing online collaborators, Barros and Verdejo (2000) give no empirical evidence for the effectiveness of their asynchronous system. Jermann (2002, 2004) describes another possibility of providing feedback based on interaction data. He provides feedback on quantitative contribution behavior as well as learner-interaction during a synchronous problem solving task (controlling a traffic sign system). In an experiment, Jermann compared a group that received feedback about each individual learner's behavior. Another experimental group received feedback about the whole groups' success. He could show that a detailed feedback containing each individual's data enhanced learners' use of meta-cognitive strategies regarding problem-solving as well as discourse.

Our research group follows this line of feedback research. We[10] conducted studies to examine feedback effects on online collaborators during CSCL. One purpose of these investigations is to provide post-hoc scaffolding for subsequent problem solving. Another purpose is to use CMC, extract data from discourses and to provide abstracted views as a substitute for missing communication cues. In particular we investigated how the interaction in and the performance of small problem-based learning groups that cooperate via internet technologies in a highly self-organized fashion can be supported by means of interaction feedback as well as problem-solving feedback. 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 the groups. We chose two ways to analyze how such group histories can be used for learning purposes. First, parameters of interaction like participation behavior, learners' motivation (self-ratings) and amount of contributions were recorded and fed back in an aggregated manner as an additional information resource for the group. This data could thus be used in order to structure and plan group coordination and group well-being. Second, we tracked group members' problem solving behavior 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 for further tasks. Two studies testing our methodology in a synchronous and an asynchronous setting, respectively, are described next.

[10] The research reported in this section has been conducted in cooperation with Joerg Zumbach.

Automatic feedback in synchronous distributed Problem-Based Learning

The first laboratory experiment (Zumbach, Muehlenbrock, Jansen, Reimann & Hoppe, 2002) was designed as an exploratory study to test specific feedback techniques and their influence in an online collaboration learning environment.

For this purpose we designed a dPBL-learning environment. In a sample of 18 students of the University of Heidelberg we evaluated six groups of three members each. All students worked together synchronously via a computer network solving an information design problem. Each group was collaborating for about 2,5 hours (synchronously in one session). The task was to design a hypertext course for a fictitious company. All necessary task materials were provided online. In addition, all learning resources related to online information design were accessible as hypertext.

As a communication platform, the software EasyDiscussing was specifically developed for this experiment in cooperation with the COLLIDE-research group at Duisburg University, Germany. This Java-tool makes it possible to display a shared workspace to the whole group that can be modified by each member simultaneously. It contains drag-and-drop functions, thematic annotation cards like "text" (for general comments or statements), "idea", “pro” and “con” to structure the discussion, and it offers a chat opportunity as well (see Figure 2). All parameters are recorded in so-called "action protocols" and analyzed either directly or after the study. This makes it possible to check certain argumentative structures that become obvious during the course work, and also opens up the possibility to provide feedback based on the data produced.

Feedback parameters were gained in the following way: every 20 minutes students were asked about their motivation and their emotional state on a five item ordinal scale (parameters relating to the well-being function: “How motivated are you to work on the problem?” and “How do you feel actually?”). These were displayed to the whole group by means of dynamic diagrams (see Figure 3), showing each group member's motivation and emotional state with the help of a line graph. As a quantitative parameter supporting the production function two diagrams showed each group member's absolute and relative amount of contributions.

In order to test feedback effects we divided the groups into experimental groups that received feedback and into control groups which did not receive any feedback. Both groups had to do a pre- and post knowledge test, a test about attitudes towards cooperative learning (Neber, 1994), as well as some questions about their current motivation and emotional state. Besides our plan to test the techniques of how to provide feedback, we assumed that the experimental groups would be more productive since they were given parameters that would enable them to fulfill their well-being and production functions more easily, they. That means, they were assumed to contribute more ideas in an equally distributed manner, and show a greater amount of reflection, as far as interaction patterns were concerned, as opposed to the control groups.

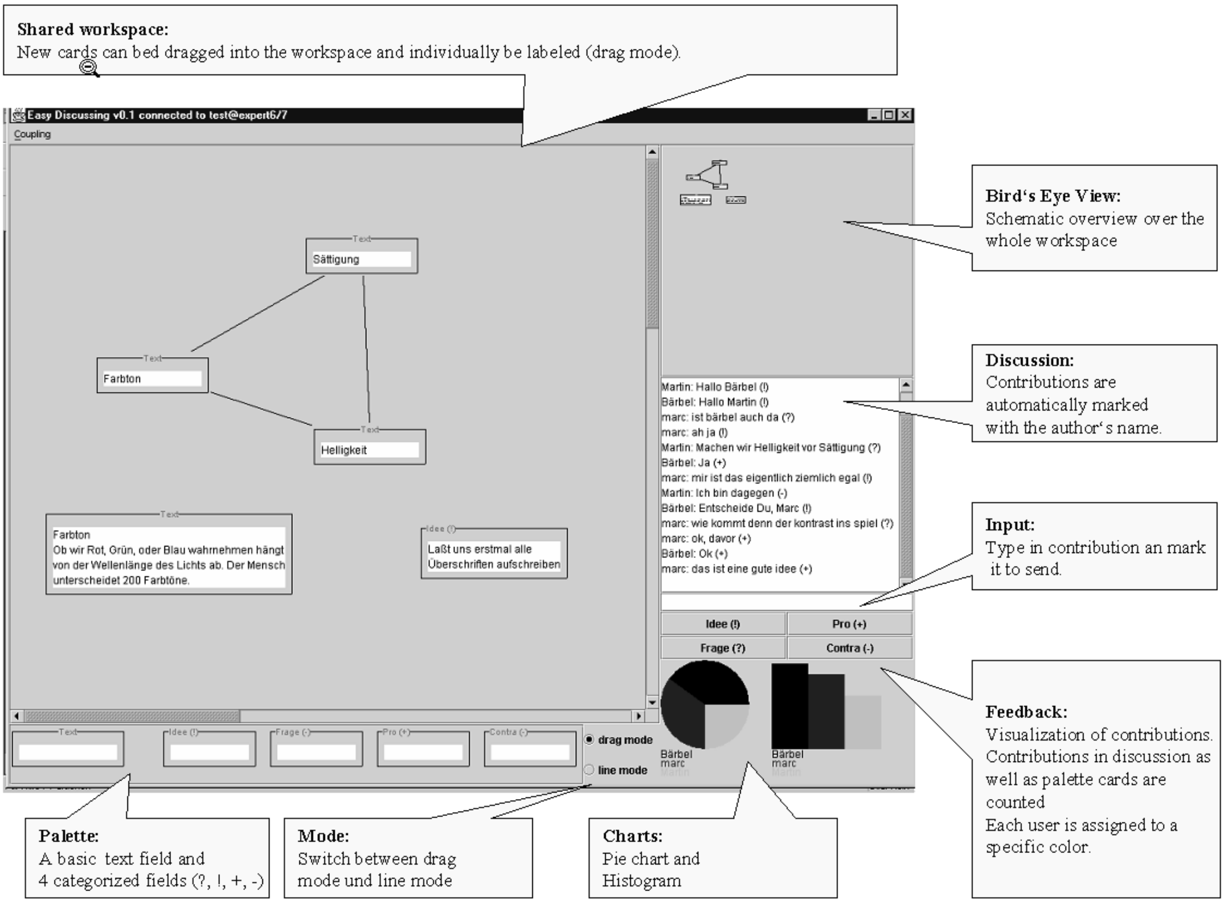

Figure 2. The design of the communication platform EasyDiscussing

The results of subjects' performance in the pre-test revealed no significant differences concerning domain knowledge. There were also no differences between both groups in post-test performance. Both groups mastered the post-test significantly better than the pre-test. There was no significant interaction between both tests and groups. We also found no significant differences regarding subjects' emotional data. The groups also showed no differences in pre- and posttests regarding motivation except a significant interaction between groups and time of measurement. While subjects in the control condition without feedback did not show differences in motivation, experimental groups had an increase from pretest to posttest. A closer look for interaction patterns in subjects' discussions revealed a significant difference in the number of dyadic interactions in groups that received feedback on their contributions.

Overall, the effects of this study indicate that some processes in computer-supported collaboration can be influenced in a positive manner by means of a steady tracking of parameters outside the task itself and immediate feedback of these to a group. Although intervention time in this experiment was short, we found positive influence of motivational feedback as well as feedback on contributions: communication patterns showed more interactive behavior for subjects of the experimental group. As a consequence of these effects, which indicate that our mechanisms have a positive influence on groups' production-function as well as group well-being, we decided to examine these feedback strategies further. For that purpose we arranged a long-time intervention study containing the same kind of visual feedback.

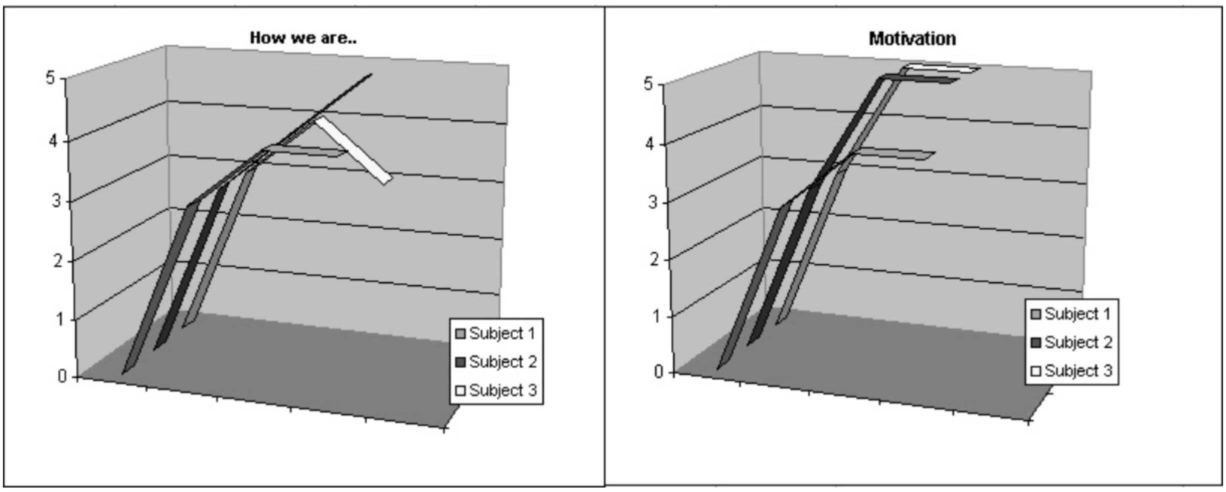

Figure 3. Feedback on emotion and motivation

Investigating the role of feedback mechanisms in long-time online learning

Our main objective in this study was to test different treatment conditions concerning feedback with groups that collaborated solely through an asynchronous communication platform over a period of four months. In this study we examined groups from three to five members – 33 participants overall. These groups participated in a problem-based course about Instructional Design that was conceived a mixture of PBL and Learning-By-Design. Learners were required to design several online courses for a fictitious company. These tasks have been presented as problems within a cover story. Each problem had to be solved over periods of two weeks (i.e. an Instructional Design solution had to be presented for the problem). As in study one, all materials were accessible online and, additionally, tutors were available during the whole course to support the students if questions emerged. At the end of each task, the groups presented their results to other groups. The asynchronous communication facility was based on a Lotus Notes® platform merging tools that can manage documents with automatic display possibilities for interaction parameters and problem-solving protocols (see Figure 4).

All documents as well as attachments were accessible over the collaboration platform. Meta-information showed when a document was created and who created it, so that interaction patterns became obvious and could be recorded. With the same technique of diagrams as in the former study, motivational and quantitative production parameters can be fed back to the user, referred to as *interaction histories*. Students' problem-solving behavior, however, had to be analyzed by the tutors themselves and had to be provided as text documents (*design histories*) in the group's workspace. Invisible for the students, a detailed action protocol was recorded in the background and was available later for analysis.

The groups were randomly assigned to one of four treatment conditions: with interaction history only, with design-history only, with both histories and without any feedback histories, i.e. a 2x2 design with the factors interaction history and design history. Several quantitative and qualitative measures to assess motivation, interaction, problem solving, and learning effects were collected before, during and after the experimental phase on different scales such as the student curriculum satisfaction inventory (Dods, 1997) or an adapted version of the critical thinking scale (Newman et al., 1997). We tried to answer the following question: What kind of influence does the administration of feedback in form of design and interaction histories, as well as their different combinations, have on students' learning? Generally, we assumed that groups with any form of histories would perform better than those without, especially as far as the motivational and emotional aspects supporting the well-being function and the production aspects supporting the production function of a group are concerned.

The results show encouraging outcomes in favor of the application of feedback within the group process. Groups that were shown design histories on their workspaces present significantly better results in knowledge tests, created qualitatively better products in the end, had produced more contributions to the task, and expressed a higher degree of reflection concerning the groups' organization and coordination. At the same time, the presence of interaction histories influenced the group members' emotional attitude towards the curriculum and enhanced their motivation for the task. Slight influences of the interaction history’s visualization regarding number of contributions were also found on the production-function: Learners receiving this feedback produced more contribution than their counterparts without feedback. So far, it seems reasonable to conclude that the different kinds of feedback influence different aspects of group behavior. Whereas feedback in form of design histories seem to influence a group's production function according to McGrath's (1991) conception of group functions, feedback in form of interaction histories seems to have an effect also on the production-function, but mainly on the group's well-being function

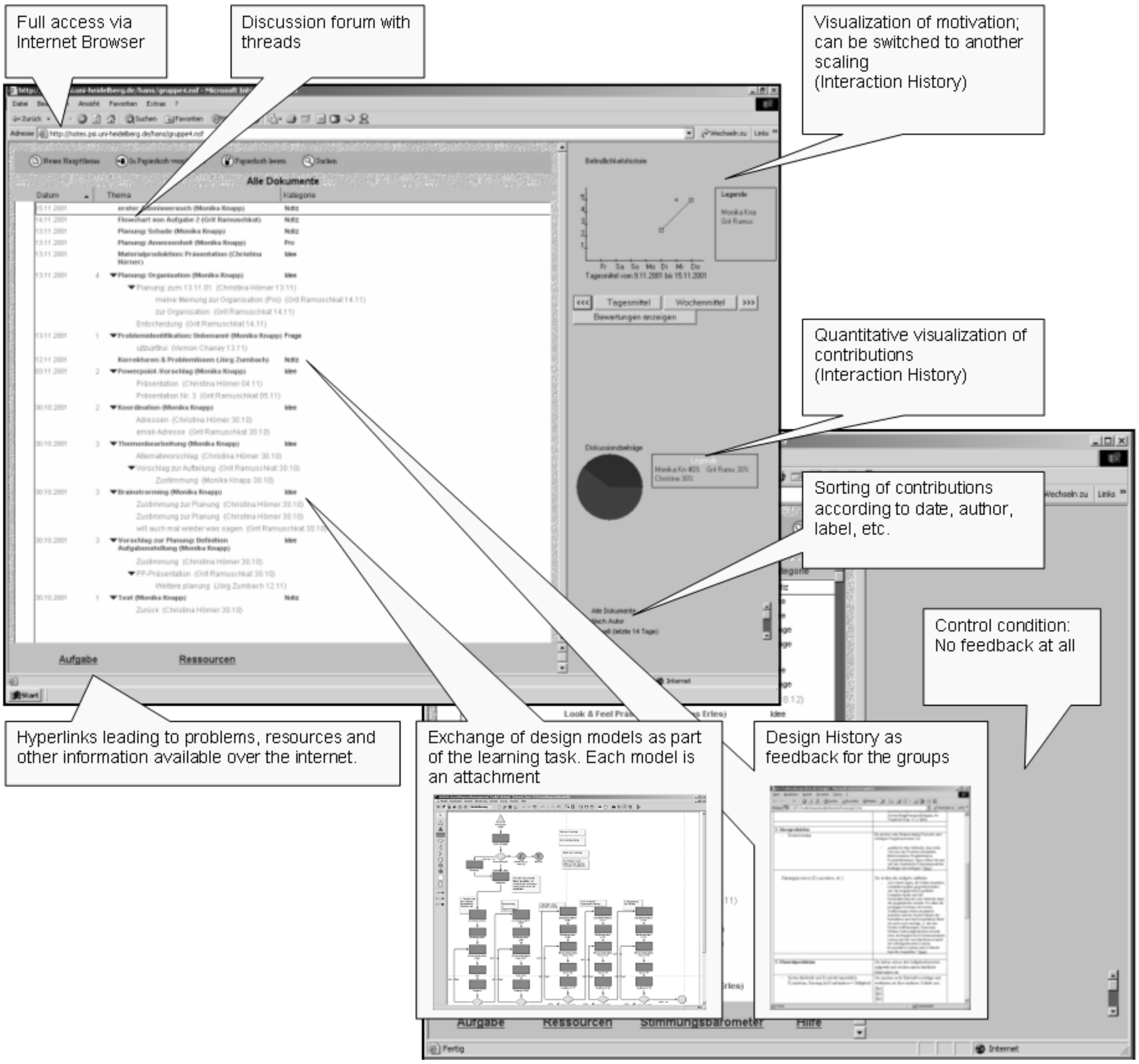

Figure 4. Asynchronous collaboration platform with feedback mechanisms.

TOWARDS ADAPTIVE VISUALISATION SUPPORT

In authentic, long term group work, it is the norm that people make use of a rich, diverse collection of communication systems, such as chat, discussion forums, and video conferencing. It is also typical that they make use of a range of tools and representational notations within one medium including, for example, written text and diagrams. We (Reimann, Kay, Yacef & Goodyear, in press) believe it is critical to begin to explore group support systems that can operate in the context of such media richness, exploiting the potentially huge amounts of data that could be available. We are particularly interested in three classes of learning that could occur in such situations:

- Learning to solve problems in a domain more effectively;
- Learning about the team, its members, and effective ways of cooperating and collaborating;
- Learning to use communication media and representational notations that match the demands of the tasks at hand, including tasks of member and collaboration management.

A number of researchers in the field of Computer-Supported Learning (CSCL) have begun to address this issue of collaboration management. Managing on-line collaboration by means of intelligent support can take a number of forms: mirroring, metacognitive and advice tools (Jermann, Soller & Muehlenbrock, 2001). They all require the ability to trace the interaction between the team members at some level of detail. We are building upon this work and intend to extend it into two directions: Firstly, in addition to supporting member interaction directly with feedback and/or advice systems, there is a need for learners to develop skills in choosing the right communication medium and tool for the situation at hand. Approaches to collaboration management that rely on a single communication medium, and/or on strongly restricted notational systems used for communicating (Conklin, 1993; Kuminek & Pilkington, 2001) need to be extended, because groups typically do not accept such limitations over longer stretches of time (Buckingham Shum, 1997). Having the choice among various communication and representation systems, however, adds to the demands groups face: they now have to deal with the additional issues of task-to-media fit (Daft & Lengel, 1984) and task-to-representation fit (Suthers, 2001). Secondly, we address human-computer interface issues extensively; not only because the management of task and interaction information distributed across various communication media raises serious attention and cognitive load issues, but also because of the social signals that come with using certain media (Robert & Dennis, 2005) and which have not been reflected sufficiently in research on computer-supported learning. We suggest an approach where the shared interface can be adapted to the needs of the work on the task as well as to the needs of interaction and member management. In the absence of a conclusive research base to derive advice from, our short term goal is to create an environment where such phenomena can be studied under controlled conditions and to experiment with various ways of visualizing information for groups and facilitators/moderators.

Adaptive Collaboration Visualisation

There has already been some work towards adaptive systems to provide advice on collaborative learning, for example (Constantino-Gonzalez, Suthers & Escamilla, 2003). There has also been recognition of the importance of social parameters, such as participation patterns (Barros & Verdejo, 2000). We will explore the use of adaptive information presentation using visualisations of the collaboration. These seem particularly promising because they are easier to implement than advice systems and no normative model of collaboration is required.

What to record. We are working on finding research-based answers to three questions around the process: (1) What to record about the learners' performance; (2) How to aggregate and then analyse the traced information; (3) What and how to visualize the results from step 2, in a manner that is adapted to the group's needs. With respect to question (1), we propose to capture *all* task- and group-related exchanges available, regardless of whether these involve the whole group, sub-groups, or individual members. Since we expect to be able to motivate the group members to help monitor their own interactions, we will be able to encourage the use of tools that we have set up to capture a rich record of interactions.

How to aggregate. An immediate effect of this is that we have to deal with large amounts of information. This must be analysed and summarised. Our approach with respect to question (2) is to collect the full set of available, un-interpreted data and then to perform a series of analyses to create both individual learner models and collective group models. We will use machine learning and data mining techniques (association rules, classification and clustering techniques such as hierarchic clustering, k-means, decision trees and data visualisation in particular) to identify patterns in groups' performance and relate those to outcome measures such as the quality of the groups' decision models and participants' satisfaction with the group process. Data mining and machine learning techniques have been successfully used for user modelling and, to a lesser extent, in education contexts. In particular, mining data based upon learners' interactions with a learning environment is promising (Bull, Brna, & Pain, 1995a).

Since a user model captures the system's beliefs about the learner's knowledge, beliefs, preferences and other attributes, it has the potential to play an important role in providing external representations of the individual and group learner models relevant to the group interaction and learning. There has been a growing appreciation of this possibility, with learner models being shared with learners in order to support reflection (Bull et al., 1995a; Bull, Brna, & Pain, 1995b, Crawford & Kay, 1993; Kay, 1995) and to help learners work collaboratively (Bull & Broady, 1997). The challenges in this project are to mine the available data sources to support the construction of a student model (Kay & Thomas, 1995), to provide natural interfaces that enable learners to see and understand the externalised form of that model (Uther & Kay, 2003), to explicitly contribute to it and, finally, but most importantly, to improve our understanding of the ways that this externalised user model can support learning and as well as the operation of the group.

What and how to visualize. Once relevant information is identified, the challenge remains how to communicate this back to the group (question 3). While the question of information visualisation has been researched before, including our own work (Uther & Kay, 2003; Zumbach & Reimann, 2003), research has so far been mainly limited to analysing individual displays of task and participation parameters (Jermann, 2004). The overall configuration of information displays – the interface elements that make up the shared work space – has been assumed as being static. We propose to dynamically adapt not only the content of individual information displays, but the *overall configuration* of information displays. For instance, when the group has to work on complex information together, social information should be reduced (in the absence of conflicts or member problems) so that all the cognitive resources can go into task information processing. Similarly, if interaction problems require attention, then the task information should temporarily be reduced and social information should be displayed with greater salience and detail. If both the task representation(s) and the social information representation(s) are properly adapted, then it should be feasible to provide suitable tradeoffs between the cognitive effort for the core task versus that for processing group and member information.

We also propose to differentiate more systematically between ‘person awareness’ and ‘team awareness’. For instance, the video/audio display of a user – as a “rich” medium (Daft & Lengel, 1984) – primarily provides information about an *individual* group member. It does not depict information about the team as such. The user lists that are part of most chat tools, however, are a rudimentary *team awareness* component – showing who is currently “in” the group activity. Visualisations can, and probably should, play a much stronger role in supporting team awareness. For instance, Erikson and Kellogg (2000) make a number of suggestions on how to visualize social configurations of team members in digital spaces such as chat rooms.

Our current prototype collaboration environment comprises various synchronous and asynchronous communication and information representation tools, including a “digital table” that allows for co-located teamwork. We are experimenting with a number of computational approaches to aggregate collaboration information and identify psychologically and pedagogically meaningful patterns and trajectories. We are also developing means for visualising information relevant for task-, team-, and person-awareness. Building on these, we will experiment with ways to dynamically modify the respective information displays to make the overall interface adaptive to situational parameters (cognitive load, social conflicts, member problems) and to group members’ preferences and individual needs.

CONCLUSIONS

In this paper, we have mainly looked at factors that apply to all forms of distributed collaborative learning, and have in particular dealt with issues that result from a lack of social awareness. While net-based group learning offers exciting opportunities to foster communication and reflection, one should not ignore the psychological challenges that arise from loosing face-to-face contact. In our recent work, we are also devoting increasing attention to the management of the user interface since adding all kinds of meta-information (helpful for reflection) to an already crowded screen space raises serious usability issues.

More would need to be said about the function of shared external representations, such as the symbols that appear on a shared whiteboard. Such shared representations do not only serve as a representation of shared knowledge, and thus play an pivotal role for grounding, they also help the group members to co-ordinate their work and to drive the agenda. The relation between such representations and the actions taken by group members need more attention in future research.

References

Barron, B. & Sears, D. (2002). Advancing understanding of learning in interaction: How ways of participating can influence joint performance and individual learning. In G. Stahl (Ed.), *Computer support for collaborative learning: Foundations for a CSCL community* (pp. 593-594). Hillsdale, N.Y.: Erlbaum.

Barros, B. & Verdejo, M. F. (2000). Analysing student interaction processes in order to improve collaboration. The DEGREE approach. *International Journal of Artificial Intelligence in Education, 11*, 221-241.

Buckingham-Shum, S. (1996). Design argumentation as design rationale. In A. Kent & J. G. Williams (Eds.), *The encyclopedia of computer science and technology* (Vol. 35, Supp. 20, pp. 95-128). New York: Marcel Dekker.

Buckingham Shum, S. (1997). Balancing formality with informality: User centred requirements for knowledge management technologies. *AAAI Spring Symposium (Mar. 24-26, 1997), Stanford University, Palo Alto, CA*. AAAI Press.

Bull, S., Brna, P., & Pain, H. (1995a). Extending the scope of the student model. *User Modelling and User-Adapted Interaction, 5*(1), 44-65.

Bull, S., Brna, P., & Pain, H. (1995b). Mr Collins: a collaboratively constructed, inspectable student model for intelligent computer assisted language learning. *Instructional Science, 23,* 65-87.

Bull, S. & Broady, E. (1997). Spontaneous peer tutoring from sharing student models. In B. du Boulay & R. Mizoguchi (Eds.), *Proceedings of the International Conference on Artificial Intelligence in Education* (pp. 143 – 150). Amsterdam: IOS Press.

Cohen, E. G. (1994). Restructuring the classroom: Conditions for productive small groups. *Review of Educational Research, 64,* 1-35.

Conklin, E. J. (1993). Capturing organizational memory. In R. M. Baecker (Ed.), *Groupware and computer-supported cooperative work* (pp. 561-565). San Francisco: Morgan Kaufman.

Constantino-Gonzalez, M., Suthers, D. & Escamilla, J. (2003). Coaching web-based collaborative learning based on problem solution differences and participation. International *Journal of Artificial Intelligence in Education, 13*(2-4), 263-299.

Crawford, K., & Kay, J. (1993). Metacognitive processes and learning with intelligent educational systems. In P. Slezak, T. Caelli & R. Clark (Eds.), *Perspectives on Cognitive Science* (pp. 63-77). Ablex Publishers.

Daft, R. L. & Lengel, R. H. (1984). Information richness: A new approach to managerial behavior and organizational design. *Research in Organisational* Behavior, 6, 191-233.

Diehl, C., Ranney, M., & Schank, P. (2001). Model-based feedback supports reflective activity in collaborative argumentation. In P. Dillenbourg, A. Eurelings, & K. Hakkarainen (Eds.), *European perspectives on computer-supported collaborative learning* (pp. 189-196). Universiteit Maastricht, the Netherlands.

Dobson, M., & McCracken, J. (1997). Problem based learning: A means to evaluate multimedia courseware in science & technology in society. In T. Muldner & T. C. Reeves (Eds.), *Educational Multimedia & Hypermedia*. Calgary: AACE.

Dods, R. F. (1997). An action research study of the effectiveness of problem based learning in promoting the acquisition and retention of knowledge. *Journal of the Education of the Gifted, 20*(4), 423-437.

Erikson, T. & Kellogg, W. A. (2000). Social translucence: An approach to designing systems that mesh with social processes. *ACM transactions on computer-human interaction, 7*(1), 59-83.

Jermann, P. (2002). Task and interaction regulation in controlling a traffic simulation. In G. Stahl (Ed.), *Computer Support for collaborative learning: Foundations for a CSCL community* (pp. 601-602). Hillsdale, NJ: Erlbaum.

Jermann, P. (2004). *Computer support for interaction regulation in collaborative problem-solving*. University of Geneva, Switzerland.

Jermann, P., Soller, A. & Muehlenbrock, M. (2001). From mirroring to guiding: a review of the state of the art technology for supporting collaborative learning. In P. Dillenbourg, A. Eurelings & K. Hakkarainen (Eds.), *European Perspectives on computer-supported learning* (pp. 324-331). Maastricht: University of Maastricht, the Netherlands.

Johnson, D. W. & Johnson, R. T. (2004). Cooperation and the use of technology. In D. H. Jonassen (Ed.), *Handbook of research for educational communication and technology* (pp. 785-812). Mawah, NJ: Lawrence Erlbaum Associate.

Jonassen, D. & Remidez, H. (2002). Mapping alternative discourse structures onto computer conferences. In G. Stahl (Ed.), *Computer Support for collaborative learning: Foundations for a CSCL community* (pp. 237-244). Hillsdale, NJ: Erlbaum.

Kay, J. (1995). The um toolkit for cooperative user modelling. *User Modelling and User-Adapted Interaction, 4*(3), 149-196.

Kay, J., & Thomas, R. C. (1995). Studying long term system use. *Communications of the ACM, 38*(7), 131–154.

Kuminek, P. A., & Pilkington, R. M. (2001). Helping the tutor facilitate debate to improve literacy using CMC. In T. Okamoto, R. Hartley, Kinshuk & J. P. Klus (Eds.), *Proceedings of the IEEE International Conference on Advanced Learning Technologies* (pp. 261-263). Madison, USA: IEEE Computer Society.

McGrath, J. E. (1991). Time, interaction, and performance (TIP). A theory of groups. *Small Group Research, (22)*2, 147-174.

Neber, H. (1994). Entwicklung und Erprobung einer Skala für Präferenzen zum kooperativen und kompetitiven Lernen [Developing and testing a scale for kooperative and competitive learning]. *Psychologie in Erziehung und Unterricht, 41*, 282-290.

Newman, D. R., Johnson, C. Webb, B., & Cochrane, C. (1997). Evaluating the quality of learning in computer supported co-operative learning. *Journal of the American Society for Information Science, 48*, 484-495.

Pfister, R., and Mühlpfordt, M. (2002). Supporting discourse in a synchronous learning environment: The learning protocol approach. In G. Stahl (Ed.), *Computer Support for collaborative learning: Foundations for a CSCL community* (pp. 581-582). Hillsdale, N.J.: Erlbaum.

Reimann, P., Kay, J., Yacef, K., & Goodyear, P. (in press). Adaptive visualisation support for self-managed learning groups. *Proceedings of the 12th International Conference on AI in Education.* Amsterdam, the Netherlands.

Reiser, B. (2002). Why scaffolding should sometimes make tasks more difficult for learners. In G. Stahl (Ed.), *Computer Support for collaborative learning: Foundations for a CSCL community* (pp. 255-264). Hillsdale, N.J.: Erlbaum.

Reiserer, M., Ertl, B. & Mandl, H. (2002). Fostering collaborative knowledge construction in desktop videoconferencing. Effects of content schemes and cooperation scripts in peer-teaching settings. In G. Stahl (Ed.), *Computer Support for collaborative learning: Foundations for a CSCL community* (pp. 379-388). Hillsdale, N.J.: Erlbaum.

Robert, L. P. & Dennis, A. R. (2005). Paradox of richness: a cognitive model of media choice. *IEEE Transactions on Professional Communication, 48*(1), 10-21.

Rummel, N., Spada, H., Hermann, F., Caspar, F. & Schornstein, K. (2002). Promoting the coordination of computer-mediated interdisciplinary collaboration. In G. Stahl (Ed.), *Computer support for collaborative learning: Foundations for a CSCL community* (pp. 558-560). Hillsdale, N.J.: Erlbaum.

Suthers, D. D. (2001). Towards a systematic study of representational guidance for collaborative learning discourse. *Journal of Universal Computer Science, 7*(3), 1-23.

Uther, J. & Kay, J. (2003). VlUM, a web-based visualisation of large user models. In *Lecture Notes in Computer Science* (Vol. 2702, pp. 198-202). Springer-Verlag GmbH.

Zumbach, J., Mühlenbrock, M., Jansen, M., Reimann, P. & Hoppe, H.-U. (2002). Multidimensional tracking in virtual learning teams. In G. Stahl (Ed.), *Computer support for collaborative learning: Foundations for a CSCL community* (pp. 650-651). Hillsdale, N.J.: Erlbaum.

Zumbach, J. & Reimann, P. (2003). Influence of feedback on distributed problem based learning. In B. Wasson, S. Ludvigsen & U. Hoppe (Eds.), *Designing for change in networked learning environments (pp. 219-228).* Dordrecht: Kluwer.