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# Computer-Supported Collaborative Concept Mapping: Study of Synchronous Peer Interaction

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*Abstract*

The paper studies undergraduate students' synchronous peer interaction using a shared Activity Space and a text communication tool. Several groups of students collaborated in order to accomplish a data-modelling task in the context of a Databases University undergraduate course. The paper presents the collaboration support environment, i.e. a concept-mapping tool, used in this study. Subsequently, evaluation of the effectiveness of the environment in the educational process is discussed along various dimensions, like group synthesis, task control, content of communication, roles of the students and the effect of the tools used. Special emphasis is given in the ways the tools and the representations used complement each other and support the process. A discussion on the use of computer-supported collaborative problem solving environments is also included.

**Keywords:** concept mapping, computer-supported collaborative learning, human-computer interaction, problem solving, open learning environments

## Introduction

Recent approaches of teaching and learning put emphasis in activities that take place in a collaborative frame (Scardamalia and Bereiter, 1994; Dillenbourg *et al.*, 1996; Lewis, 1997) and relate to problem solving. Collaborative learning approaches seem to encourage knowledge construction and deep understanding, while they support active learning and deep-level information processing. They also require from learners considerable cognitive effort. From a cognitive perspective the process of collaborative learning, involving peer student interaction, can be considered as a process of co-construction of knowledge through convergence of transformed knowledge of the learners involved (Roschelle, 1992).

Collaborative learning can lead to better development of ideas and concepts through discussion and negotiation. In this context, skills of critical thinking, communication and coordination as well as mechanisms of knowledge construction can be developed. In addition, through collaborative learning validation of individual ideas, verbalization of

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thoughts, multiple perspectives, cognitive restructuring, argumentation and concept conflict resolution can be supported (Steeples and Mayers, 1998).

Collaborative learning takes new forms in contemporary technological environments, which support communication and interaction. Computer-supported collaborative learning (CSCL) is based on the idea that computer applications can be used as scaffolding and can support socio-cognitive processes for knowledge sharing and knowledge building (Scardamalia and Bereiter, 1994; Paavola *et al.*, 2002). These applications permit computer-mediated communication (CMC) between humans working together in the same or different locations with a joint objective. Collaborative processes have become possible through environments of CSCL that permit "distributed" and distance learning (Anderson and Jackson, 2000).

A case worth special attention is related to collaborative development of diagrammatic representations, like concept maps (Novak, 1990; McAleese, 1998, etc.). An important aspect of knowledge construction in this context relates to the identification of activities (Gifford and Enyedy, 1999) that help the students externalize their thinking and develop dialogue practices. A large part of this process involves students' sense-making activities, like discussion on external representations that contain symbols, concepts, models and relations (Gay and Lentini, 1995; Suthers and Hundhausen, 2002). The representations utilized by the students to communicate in this context play an essential role. In general the creation of abstract representations like visualizations is a key to collective problem solving (Schwartz, 1995). Schwartz also observed that students who draw sketches to represent a problem were more successful than students who did not use diagrammatic representations. The act of sketch drawing resulting from a common representation of the problem has helped students to create a mechanism for "construction of shared representation". The process for constructing a diagram (concept map, data flow diagram, entity–relationship diagram, etc.) can be considered as a tool for social thinking. These diagrams maintain many characteristics of engineering design representations that have been described as interactive communication tools and individual thinking tools (Roth and Roychoudhury, 1992). Under this perspective, diagrams that represent scientific concepts, built through collaboration, are a medium for task organization and creation of the final product. Such diagrams support group thinking and therefore constitute distributed cognition tools (Gasser, 1992). The structure of the diagram can be considered as part of the distributed problem solving space since it permits the users to work simultaneously in the same problem. So the diagram provides a *shared conceptual space* in which the problem solvers can refer through shared objects, gestures or words (Roth and Roychoudhury, 1992).

Support for synchronous collaboration of students with the aim of constructing diagrammatic conceptual representations or other shared solutions into a common space is a new challenge. Based on this perspective, *Representation 2.0 (R2)*, an innovative environment supporting collaborative creation of diagrammatic conceptual representations has been developed (Fidas and Komis, 2001). This environment has been used experimentally to support collaborative problem solving under real educational conditions. The study, its findings and their implications on the design of other similar computer-based collaboration support environments are the subject of this paper. In the next section the software environment (Representation v. 2.0) is briefly described, followed by an outline of the context of the study. Next the results of the study are presented, while discussion of the findings and implications of the study are included in the final section of the paper.

## The Representation 2.0 Collaborative Concept Mapping Environment

*Representation – version 2.0 (R2)*[1] is an educational software supporting collaborative concept mapping. R2 design draws from a pedagogical framework supporting the active engagement of the students in the creation of their knowledge (within the perspective of constructivist theories of learning) and from the position that the social interaction mediates learning through socio-cognitive conflicts (Doise and Mugny, 1984). R2 has been used to study, both in collaborative and individual user mode, building of semantic representations in various educational contexts and for study of collaborative learning. The design principles of R2 have also influenced the ModelsCreator (Komis et al., 2001) and ModellingSpace (www.modellingspace.net) educational environments. Typical user view of the R2 environment is shown in Figure 1.

The R2 environment provides tools for individual and collaborative expression of knowledge through diagrammatic representations. The objects supported in the diagrammatic representations are *node objects* (concepts) and *link-objects* that connect them. Libraries

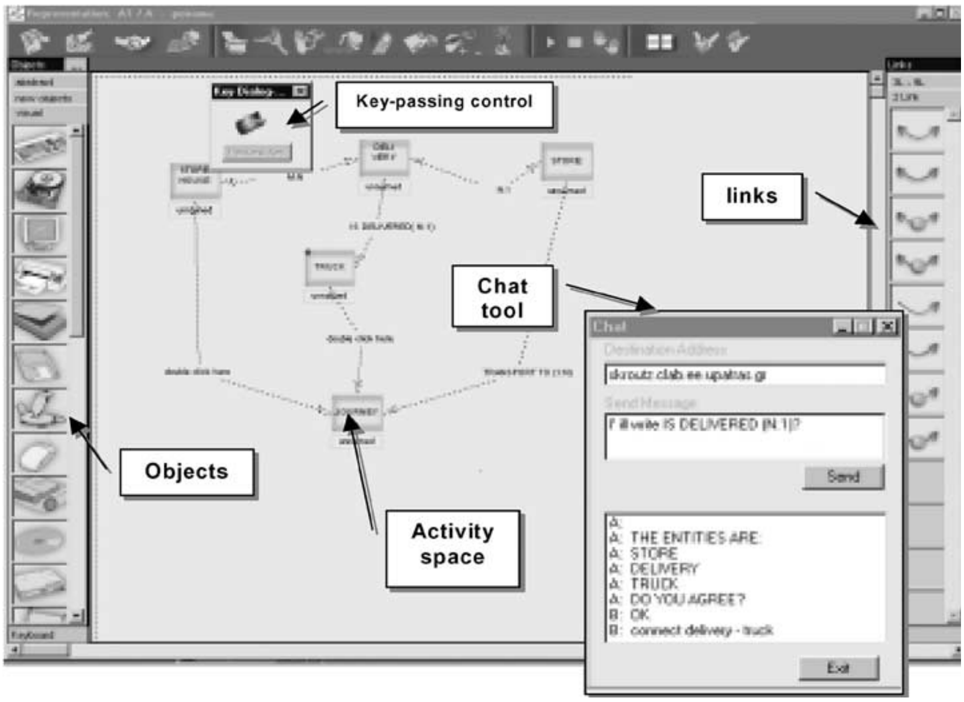


*Figure 1.* The R2 user interface.

of such objects are already provided to the users of R2. These libraries can be extended by the users. The tool has been used for expressing in a diagrammatic way *concept maps* (Novak, 1990; McAleese, 1998), *semantic networks* (Fisher, 1990), *entity–relationship diagrams* (Chen, 1976), etc.

The diagrams developed through R2 can be made of multiple levels: It is possible to associate a new diagram of a lower level to an object. The multi-level diagrams created through this tool can be complex conceptual constructs, navigable by the users.

A log file of the diagram creation process is automatically created and saved together with the diagram. This can be used by the teacher/researcher as a cognitive tool providing useful information regarding the development of the student involved. An extract of such logfile is shown in Figure 2. These logfiles have been the main source of information for our study, as discussed in the following sections of the paper.

The tool provides facilities for synchronous and asynchronous interaction between collaborating partners engaged in problem solving. In the synchronous interaction mode, the environment supports simultaneous development of diagrammatic representations of dispersed collaborating partners through the use of a shared *Activity Space* (Plöetzner *et al.*, 1996; Muehlebrock and Hoppe, 2001). The *shared Activity Space* is a shared window where each of the two collaborating partners can insert and modify objects (concepts and links) out of primitive objects creating multi-layer diagrams, through direct manipulation.

In addition, dialogue and negotiation is supported through a *chat tool* that permits exchange of free-text communication messages between collaborating partners.

When a connection between two peers is established, following a "request for collaboration", a copy of the activity space is built and maintained in both sides, until the connection

```
....
122 )    12 : 55 : 41     00 : 32 : 11  Renamed Relation: Doted
                                          from : double click here
                                          to :own              by user :User C
                          C:  STOREHOUSES DO NOT SELL
                          D:  the departments sell products
123 )    12 : 57 : 18     00 : 33 : 48  Renamed Relation: Doted
                                          from : contains
                                          to :sell             by user :User C
                          D:  i don't think that is necessary to link
                          D:  Velo with products
124 )    12 : 59 : 20     00 : 35 : 50  Insert Map Rectangle 1 ( Level 1 ) by user :C
                          C:  TO LINK WHAT?
125 )    13 : 00 : 04     00 : 36 : 34  Level Up  ( Current Level 0)
                          C:  WE HAVE ALREADY LINKED VELO
                          C:  WITH PRODUCTS
126 )    13 : 01 : 18     00 : 37 : 48  Rename object: Rectangle 1
                                          from : VELO
                                          to :VELO             by user :User C
127 )    13 : 01 : 18     00 : 37 : 48  Rename object: Rectangle 1
                                          from : unnamed,
                                          to :unnamed          by user :User C
128 )    13 : 01 : 20     00 : 37 : 50  Insert Map Rectangle 1 ( Level 1 ) by user C
129 )    13 : 01 : 22     00 : 37 : 52  Added object: Ellipse 1by user :User C
130 )    13 : 01 : 54     00 : 38 : 24  Rename object: Ellipse 1
                                          from : double click here
                                          to :director         by user :User C
....
```

*Figure 2.* An extract of the log file of student interaction with R2.

is terminated by one of them. The two partners can exchange roles, being either the passive or the active one. The active partner can manipulate objects in the activity space. Her actions generate control messages transmitted to the passive partner, thus reproducing the same effect at the screen of both workstations. The exchanged messages are kept small (a few bytes) since only changes in the state of the activity space are transmitted. A typical message can be "Object of type J inserted in position X,Y", while the object J itself is not sent, as copies of object libraries are maintained in both sides. This way under low bandwidth connections the two peers can still have the feeling of instant interaction and a shared WYSIWIS (what you see is what I see) environment, unlike other environments that require high bandwidth connection in order to achieve the same effect.

A mechanism is also provided for exchange of roles among the partners. The metaphor used is that of "passing the key" (Heeren and Collis, 1993). The holder of the "action-enabling key" is the active partner. Through this key-request protocol the active role can change at any point during collaboration, provided that the passive partner requests the key and the active partner accepts the request. This facility is used in order to avoid conflicts observed in synchronous activity environments (Soller, 2001). The implemented protocol in R2 maintains clear semantics of actions and roles in the shared activity space, while it imposes explicit interaction relating to key exchange. One of the objectives of our study has been to examine the nature of this key-exchange interaction and its effect on collaboration.

Integration of the described collaborative learning tools in the same environment and consequently the capability of the environment to log all user activity in the Activity Space together with the synchronous/asynchronous communication actions as shown in Figure 2 makes R2 a suitable testbed for collaborative problem solving research, as demonstrated by this study.

## The Evaluation Study

### *Objectives of the study*

The main objective of the study was to evaluate the effectiveness of synchronous collaboration, through R2, in an educational context and identify the characteristics of the collaborative problem solving activity that can be supported by this environment and the developed problem solving strategies. The focus has been in particular on tracking the development of mutual understanding among groups and on establishing how the collaborative problem solving was influenced by the use of the available diagrammatic and textual communication tools.

Our sources of data for this study were:

(a) The *logfiles*, which captured inter-group communication acts, shared Activity Space actions, and control actions like key requests.
(b) The produced solutions to the given problem by the student groups.
(c) Field observations of the problem-solving activity and intra-group interactions.

In the frame of the reported study, the interaction between collaborating groups was done through acting on the shared representation of the problem solution and exchanging text messages. The dialogues developed involved interleaving of both direct-manipulation actions and communication-acts, as observed often in this kind of collaboration environments (Rogers and Ellis, 1994). Special emphasis is given during this analysis in techniques for study of such interleaved multiple-representation-based interaction.

*The context of the study*

The study took place in the frame of the Laboratory of the Undergraduate course "Data and Knowledge Based Systems" of the ECE Department of the University of Patras. Seventeen (17) students participated in the study during a scheduled laboratory session. Fourteen (14) of them formed seven (7) two-member groups while the rest three (3) worked individually. These ten (10) groups were dispersed in the computer lab and interacted in pairs during a two-hour session using exclusively the R2 environment, in order to tackle a given problem, described in Appendix A. There were seven two-member groups (A, C, D, E, F, G, H) and three individual students (B, I, J). Five pairs (A–B, C–D, E–F, G–H, I–J) were formed during the study. As a result, the number of students in each of them varied, A–B had three members, C–D, E–F had G–H four and I–J two. This variation allowed for studying the effect of inter-group interaction on collaborative problem solving, as discussed in the following section. Each pair of groups was asked to produce, at the end of the laboratory session, a single solution to the problem, using the collaborative problem-solving environment R2. The tools of R2 had been presented to the students during a previous session. So all students had previous experience with the tool used. All students that participated in the study were skillful computer users. They also had a good understanding of the domain of the problem and the notation of Entity–Relations (ER) diagrams to be developed, since they had solved similar problems using paper and pencil in the past.

After studying the problem description, the students had to identify the main entities, their attributes and their relationships and draw a conceptual diagram, using conventions of ER diagrams. No specific instructions were provided about the problem solving strategy to be used and the roles of the problem solving partners. Adequate time was provided for completion of the problem solving process. No intervention of the tutors was made during the study.

*Analysis methodology*

A number of complementary perspectives have been applied in the analysis of the results of this study, emphasizing qualitative analysis methods. According to Stahl (2002), the study of CSCL applications in terms of micro-analysis of conversation, of collaborative knowledge building, of mediations by artifacts and of group communication and interaction provides a rich frame for conceptualizing and studying the learning processes in CSCL environments. In our case, first analysis of inter-group interaction is provided, useful for gaining an insight into the interaction that took place and the analysis technique used. Subsequently, a goal level analysis is performed and the quality of the solution is related to the degree of interaction while the effect of group synthesis on interaction and control structures are studied. Finally the effect of the key-passing mechanism on task execution and the content of the exchanged messages are studied.

The *analysis of the dialogues* is based on the OCAF analysis framework (Avouris *et al.*, 2002a), which involved transformation of the direct manipulation operations in the common design space to equivalent communication acts when applicable. Examples are: "I propose this <object inserted>", "I accept suggestion and do <action>", or long silence after a proposal, implying acceptance. A typical pattern that was observed often in the dialogue was that as a result to a suggestion, the suggested operation was performed without any explicit verbal reply. Equivalent techniques have been suggested in (Winograd and Flores, 1986) and (Baker and Lund, 1997) who have identified the importance of actions or operations within a complex environment for the evolution of the dialogue. Baker and Lund for this purpose use the term "Communicative acts" rather than "speech acts" in order to avoid the association of the latter with exclusively spoken language. A typical application of this analysis technique is included in the next section and an extract is shown in Appendix B.

Additionally, in the *goal level analysis* the goals of the groups involved and the interactions that took place were identified and inter-related. This part of the analysis is influenced by the distributed cognition framework (Hutchins, 1991; Rogers and Ellis, 1994), which identifies the functional system as the central unit of analysis, that is the collection of the students and the computer system, supporting their interaction and problem solving activity. A distributed goal structure has been built that describes the context and the various phases of the problem solving process.

Finally various parameters describing *control*, *interaction*, *content of communication*, *balance of activity*, and *partners roles have* been identified and measured according to the collected data in the log files. The conclusions drawn from them were related to those of the other analysis perspectives, as discussed in the following section.

## Analysis of Results

### *Goal-level analysis of problem-solving strategies*

The problem-solving activity that took place during this study can be described as a construction of a sequence of mental and external models by the participants. The problem was stated through a free text representation in the handouts, containing pieces of information of varying relevance to the final solution.

It is assumed that each student built a mental model $M_i$ of the supermarket supply problem, after studying this text. Through intra-group interaction the group built a consensus on a single model, which was proposed verbally and/or by action in the shared Activity Space as the group model $M_a$, $M_b$. This was negotiated through inter-group interaction in order to be transformed into a single group model $M_c$, as shown in Figure 3. This could not however be considered a linear transformation process, since these models influenced each other. Nevertheless the inter-group model $M_c$, is the only persistent model, playing a cen-

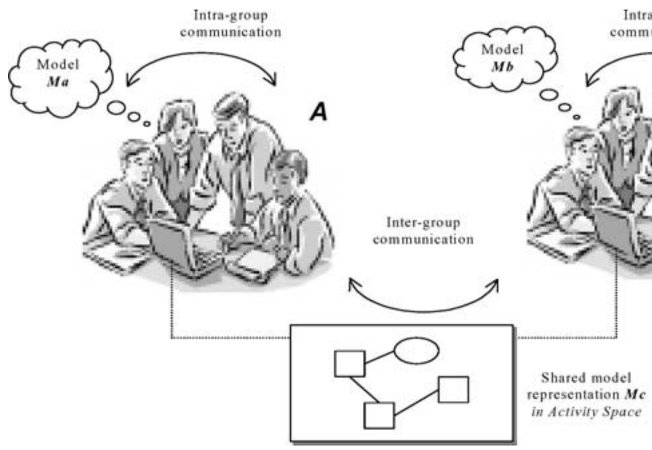


*Figure 3.* The study setting: modeling and interaction aspects.

tral role in this modeling process. Deviations were observed in the case of single-member groups, as discussed in the following.

A typical strategy related to this problem, observed in most of the collaborating teams, was the following:

(GOAL-0: Building of entity–relationship diagram of supermarket supply problem)
(SUBGOAL-1: study and discussion of the problem within a group)
(SUBGOAL-2: identification and negotiation on main entities with partner)
(SUBGOAL-3: identification and negotiation of main relationships with partner)
(SUBGOAL-4: identification and negotiation of attributes with partner)
(SUBGOAL-6: examine and discuss validity of the design)

Subgoals 3 and 4 were often interleaved. Further analysis of this goal structure involves discussion and argumentation between the group members of the entities involved, drawing of the selected entities, etc.

A task level description of a 15-min extract of activity involving group A–B is included in Appendix B, where in the column labelled "*Goal*" the current goal of the partners is shown. Analysis of this extract determines that initially both partners shared the goal of defining the key entities (G2), after studying the problem. There is no negotiation involved for determining this goal. However further on the pursued subgoal of the two partners is not common. Partner A switches to G4 (identify attributes) in order to resolve a conflict of a particular subgoal in G2. However partner B does not participate in this task shift, persisting in the G2 task, finally bringing partner A back to the main task. Finally at the end of the extract, partner B suggests through question (m53) to move to goal G3. The roles of the participants remained stable during this extract. That is, B played the role of leader/observer and A that of implementer and apprentice with some objections/remarks on the suggestions and proposals of B. It is observed that the proposed design solutions by A were made by direct operations in the design space, while those suggested by B were made verbally.

*Table 1.* Groups' interaction, key possession and activity (in columns where two numbers appear, they refer to the two collaborating partners)

| Group ID | Group size | Total time (min:sec) | Messages exchanged | Key possession (min:sec) | Actions in shared space |
|---|---|---|---|---|---|
| A–B | 2–1 | 35:40 | 15–43 | 35:40–0:0 | 192–0 |
| C–D | 2–2 | 34:56 | 11–9 | 31:09–03:47 | 92–20 |
| E–F | 2–2 | 36:02 | 22–15 | 14:32–21:70 | 40–67 |
| G–H | 2–2 | 30:56 | 11–13 | 23:40–7:16 | 118–26 |
| I–J | 1–1 | 18:15 | 18–19 | 15:54–2:21 | 29–12 |

This part of the analysis has identified the problem solving strategies of the partners and the mechanisms for controlling the problem solving process. An observation was that the activity was very much focused on problem solving, despite the lack of intervention from the tutoring staff. This is expected in the context of a University course. Another advantage of this technique is the identification of goal related negotiation and conflict resolution mechanisms, especially if combined with tool control mechanisms like the key possession, discussed next.

### *Effect of group composition on interaction and problem solving*

In this section the results of analysis of group interaction and Activity Space actions are processed in order to establish patterns of behavior and the effect of group composition in problem solving. An overview of inter-group interaction and problem solving activity, as recorded in the log files is shown in Table 1.

The solutions proposed by all groups were of varying quality but seemed to address the main issues of the problem. For completeness of the presentation a measure of performance of the four groups that completed their effort is provided here. According to a defined metric, which gives points for correctly identified entities, relations and attributes, the scores of the completed[2] solutions are: (A–B) = 9.5, (C–D) = 5.0, (E–F) = 12.5, (G–H) = 14.5, average performance = 10.4. This performance was similar to that of a number of students who have solved the same problem using a paper and pencil environment in a previous session (9 students, average performance = 10.9, no statistically significant difference).

There is a correlation between density of interaction and the composition of the groups involved. In Figure 4 the relation of the number of actions/min to the number of messages/min for each partner are shown. Two distinct clusters appear in this diagram.

The first one is that of the two-member partners, which is characterised by medium to high actions/min rate and low to medium messages/min. The other cluster contains the one-member partners, which have varying activity rates, but consistently high text communication rates. This finding was anticipated, since the intra-group communication taking place in two-member partners, results on less need for inter-group communication, while the need to contribute to the solution through this process, leads to higher activity resulting in higher rate of actions. The A–B team, which was asymmetric in composition, resulted in the most asymmetric distribution of exchanged messages, with the single-member group engaged more heavily in communication, avoiding possession of the key.

In the chart of Figure 5 the relation between key possession time and communication rate is shown. The trend in this diagram is that partners that have longer possession of the action-enabling key tend to use the text communication channel less frequently, while those with lower possession of the key tend to use the communication channel more often.

A conclusion of this study is the observed non-symmetric use of the tools in most of the teams. Some partners used more the text communication tool while others the diagram

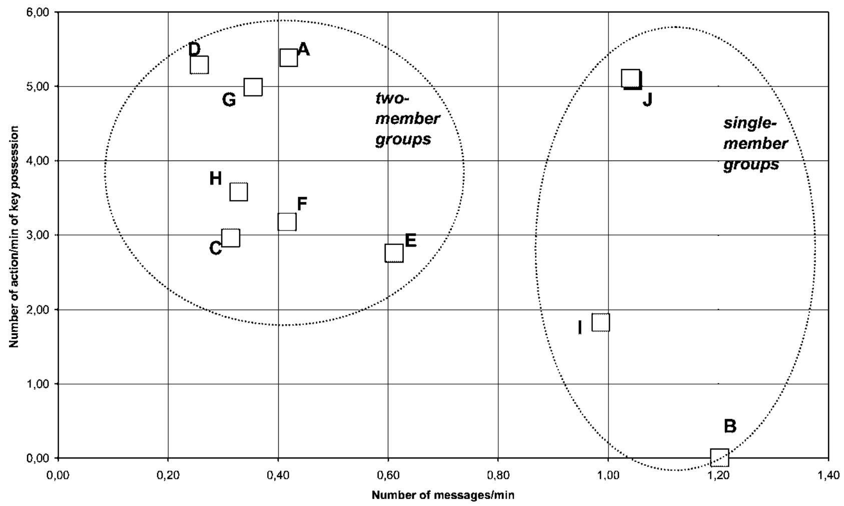


*Figure 4.* Actions per minute of key possession vs. messages per minute.

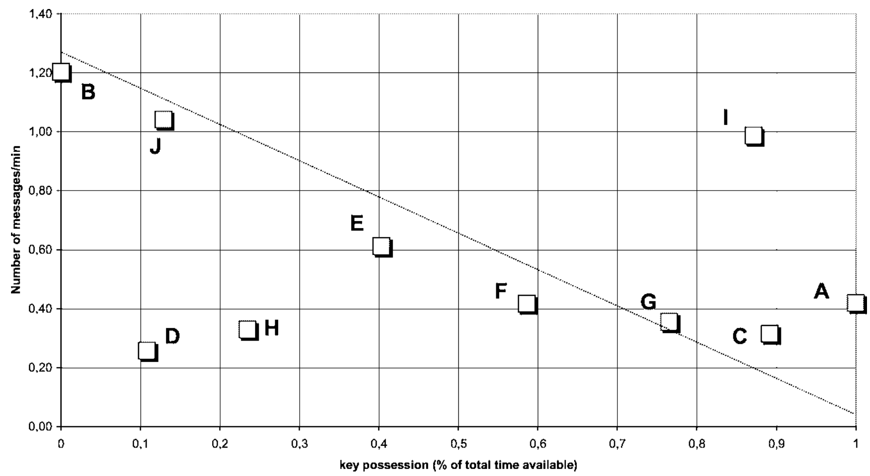


*Figure 5.* Key possession as percentage of total problem solving time vs. messages sent per minute.

building tool. The roles of the partners were accordingly influenced. Group composition has played some role in the attitude of the partners towards collaborative problem solving, since the single partners were more collaborative than the two-member groups. The latter seemed to have a tendency to discuss the solution within the group rather than with the distant partner. Finally the quality of the solution has not been affected by the degree of inter-group collaboration or the tools used, since the performance was not significantly different than that of a reference group of students that used a paper and pencil environment.

*Analysis of control and roles of partners*

With regard to key possession, the observation was that the key possession was not symmetric within the teams. In most cases one partner took the role of the actor and the other of the observer/critic of the action. In one extreme case (A–B) one partner did not ask for the key at all (distribution 100%–0%), while in other cases the possession was distributed 89%–11% (C–D), 87%–13% ( I–J), 76%–23% (G–H) and 60%–40% (E–F). This did not correspond necessarily to the degree of participation in problem solving, as demonstrated in the case of A–B team, where partner B, despite of no possession of the key, had a strong influence on the developed solution as shown by the collaboration evaluation study that identified that important model components proposed by A were 3 (33%) and by B were 6 (67%). As a consequence, the key did not change owner many times in most cases. In Table 2 this parameter is shown for the various teams.

The possession of the key does not determine the “ownership” of the built objects. On the other hand it has been observed that the key possession influenced the number of exchanged messages and the role of dialogue initiator. So an asymmetry in dialogue initiation was observed related to the key possession. In the extract of Appendix B, partner B, initiated the dialogue 4 times (m19, m30, m40, m52) versus one (m3) of A who was the key owner. So in such an environment the partners seem to make use of the available tools most according to the roles they choose to play in the process.

There have been recorded incidents, when requests for key possession were refused. In one case, (G–H team) the key was originally in possession of the group that refused many times to turn it over to their partner. Only when this behaviour resulted in deadlock (partner refused to participate in problem solving and carry on with the collaboration), the key was passed over. The reasons for key exchange varied: In some cases the reason was related with the inability of the partner to proceed with task execution and as a result offered the key. In other cases one partner was unable to express verbally his/her suggestion

*Table 2.* Key control actions per collaborating group

| Team | Key change | Key requested | Key offered | Key requested–rejected |
|---|---|---|---|---|
| A–B | 0 | 0 | 0 | 0 |
| C–D | 3 | 2 | 1 | 0 |
| E–F | 2 | 1 | 1 | 1 |
| G–H | 3 | 1 | 2 | 6 |
| I–J | 4 | 1 | 3 | 0 |

and asked possession of the key in order to demonstrate the proposal in the design space. This latter behaviour could be initiated from either part (“take the key and show me what you mean”, or “give me the key in order to show you what I mean”, were both observed behaviours).

In one case the key possession followed an “agreement” on task allocation, i.e. after a decision that partner X will complete task (a) and subsequently partner (Y) will do task (b), upon completion of task (a) the acting partner group, handled over the possession of the key. Often use of the text communication channel has been observed to be used for negotiation over key possession, instead of just using the appropriate “key request” button.

A conclusion of this part of the study was that the key has been exchanged between partners less frequently than expected. The implication is that some partners possessed the key more than others. Since the role in the problem solving was influenced by key possession, a consequence of this was that some students had more active participation in problem solving, proposing parts of the solution, while others were more passive, taking a more distant attitude towards the evolving solution. Mechanisms need therefore to be defined and supported by the environment that promote and encourage more active participation of all partners in problem solving and role exchange.

*Content of interaction*

The content of exchanged messages was also analysed. There are many frameworks for analysis of content of interaction. Two large classes of messages where identified during our study. Those related with control of interaction and problem solving and those related to task execution. In the first class, messages related to the negotiation of the problem solving strategy and task allocation were identified. Some times the process has been negotiated (“do you think we should start from entities first?” (I–J)). Or in other occasion: “We will identify the entities and we let you find their attributes” (G–H). Often the strategy was implicitly decided and no explicit negotiation was necessary. Completion of a task was often subject of negotiation “do you think there are any more attributes in this concept?”, or was implicitly decided by one partner (“let us now move to concept relations”) without any objections of the other partner.

The content of over two-thirds of exchanged messages was related to the task. This is partly due to the fact that the problem solving took place in a limited time, so the students did not spend any time discussing out-of-task matters. Also no attempt was made to identify the partners of the collaborating group, in spite of the fact that their identity was not known.

In some cases the dialogue related to the tools, e.g., “How do you move from one level to the other”? Also remarks on the appearance of the shared space were made. For instance: “Can you move entity X to the left”, etc. The observing partner who had no control of navigation as the model became more complex expressed sometimes frustration and anxiety (remarks like “Go to the higher level now!” or “Can you put the entities closer so that they can fit in the screen” were made in some cases). When there was ambiguity in free-text statements, often due to lack of pointing capabilities, the solution of exchange of key was chosen in order to demonstrate actively a proposal.

*Table 3.* Classification of exchanged free-text communication acts

| Class of communicative act | A–B | C–D | E–F | G–H | I–J | Total |
|---|---|---|---|---|---|---|
| Off-task | 0 | 0 | 0 | 2 | 1 | 3 (2%) |
| Task-related | 47 | 14 | 26 | 11 | 13 | 111 (68%) |
| Interaction-control | 10 | 4 | 10 | 11 | 12 | 47 (29%) |
| Tool-related | 1 | 0 | 1 | 0 | 1 | 3 (2%) |
| Total | 58 | 18 | 37 | 24 | 37 | |

A systematic classification of the exchanged messages was performed according to the following set of communication act categories: *off-task, task-related, interaction control* and *tool related*. This classification is inspired by the proposed classification by (Baker and Lund, 1997) to which the classification of (Chiu *et al.*, 2000) also agrees. In our classification a new class is proposed, the *tool-related* communication acts. In this class messages like "Can you truncate messages to fit in the chat box?" (A–B) or "How do I see the bottom of the diagram?" (E–F) are included.

In Table 3 the exchanged text messages are classified according to this scheme. From this table one can see that very small percentage of the messages where off-task and tool-related (4% in total). The rest 96% were problem-solving related, one third of which were related to interaction control and the other two thirds where task focused. This is an indication that the groups where focused on problem solving activities and the tools did not seem to interfere with the problem solving process.

## Discussion – Conclusions

This article reports on aspects of computer supported synchronous peer interaction in an educational context. The findings presented, may interest the growing community of researchers and practitioners who are concerned with introduction of tools and techniques of computer-supported collaborative learning in the educational process.

The capabilities of the R2 environment, and in particular its three tools provided for support of synchronous collaboration: a shared Activity Space, a text communication tool and a key control mechanism, have been proven useful in the context of the study: The groups of students managed to solve a complex problem of data modelling, exhibiting performance similar to a reference group that solved the problem using paper and pencil.

One analysis approach used included quantitative analysis and classification of the interaction density, the density of direct manipulation activity, the control possession and message content. These quantities have provided indications of the process and comparative measure of group behaviour, however they failed to provide us with the necessary insight of the complex process of collaborative problem solving.

A complementary framework of analysis used has been the transformation of activity in the shared Activity Space to equivalent communication acts. As a result of this transformation, a uniform representation of the interaction was created that facilitated analysis of discourse. Through this transformation, it was possible to capture the process of building the shared understanding and identify the contribution of various representations in the evolving solution, as demonstrated in Appendix B for the extract of interaction discussed.

An observation made following this analysis was that the key holder tends to use the *Activity Space* as a communication medium, more than the text. This is due to:

- Technical reasons, e.g., it is not possible to manipulate objects in the Activity Space, while typing in the communication space.
- The fact that switching media requires extra cognitive activity, therefore inertia is observed in the use of the communication channel.
- Direct manipulation is more effective compared to verbal argumentation in the frame of the diagram-building task.

An alternative framework of analysis was related with problem-solving strategies analysis. This was related to hierarchical goal structures, which described the problem-solving activity of the partners involved. The activity was related to the tasks of the partners and thus was characterized in terms of control and progress towards achieving the presumed goals. Also conflicts were identified and the partner roles were related to this goal structure.

Through this study the complementarily of the tools and the media/representations used for collaborative problem solving was demonstrated. In particular, the limitations of the tools seemed to determine the characteristics of interaction, while many patterns of interaction emerged. According to activity theory (Engeström *et al.*, 1999; Kuutti, 1996) and other theoretical perspectives, the selection and design of adequate communication tools is an important factor for collaboration support systems. In our study two distinct tools were used: one relating to direct manipulation interaction model, which is based on WYSIWIS (what you see is what I see) principle and one on a free-text communication model. Control of the tools has determined the roles of the partners involved in problem solving. The teams of students collaborated in various degrees without intervention of the tutors and assistants. The provided tools supported interaction in a transparent way, without interfering with the problem solving process, as the message content analysis has revealed.

While the shared Activity Space played an important role in the study, the textual communication tool has been also used effectively despite its limitations. One evident limitation in such setting was the lack of deictic power through which gestures in the shared Activity Space will be possible by the partners. So a suggestion emerging from this study is the design of adequate tools that combine multi-modal communicative acts in a single medium, improving the expressive power of the tool. One such improvement in this direction could be the addition of sticky-notes containing comments (mixing direct manipulation and free-text communication) as well as control of individual cursors by all collaborating partners, as discussed in Fidas *et al.* (2001).

Finally a finding of the study relating to the roles of the partners was that collaboration is not an automatic process that is going to take place once an adequate set of tools and a group of motivated individuals are situated in an appropriate educational context. The study demonstrated that the groups of students that took part in the study often result in not balanced societies in terms of action and communication, and therefore imbalanced participation in problem solving. Since the group members involved in our study did not have to follow a predefined pattern of organization and interaction, they took roles that were mainly determined by their communication and interaction skills, their motivation and abilities. It should be the concern of the facilitator of collaborative learning to define an appropriate complex protocol of interaction and a set of support tools that encourage a more balanced participation of all students involved in the problem solving and learning process.

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## Notes

1. The *Representation Tool* (v. 2.0) constitutes the evolution of *Representation Tool* (v. 1.0, April 2000). This software has been developed in the frame of *Représentation Project*, Educational Multimedia – Task Force (project contract 1045), European Union (http://hermes.iacm.forth.gr).
2. For technical reasons, team (I–J) did not complete their effort, so their solution was not evaluated.

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## Appendix A

*The problem solving task*

The problem solving task involved the collaborative building of a model of the activities of an imaginary goods transport company (ABC) that supplies the stores of a supermarket chain (VELO), transporting goods from a number of storehouses owned by the supermarket company to the supermarket stores. The purpose of this model is to be used in the design of a database developed for both ABC and VELO companies, in order to support them in scheduling their trucks and delivering of supplies. The students had to express the model as an entity–relationship (ER) diagram (Chen, 1976), a representation often used in data modeling. A detailed description of the activities to be modeled was provided to all students.

## Appendix B

Commented extract of interaction between partners A and B

| No | Time-line | Partner A (Actions and messages) | Partner B (Actions and messages) | Equivalent communication act | Goal |
|---|---|---|---|---|---|
| 1 | 12:40:17 | Added rectangle object – named object VELO | | *A: I propose an entity VELO* | *G1* |
| 2 | 12:41:21 | Request for collaborative work: with user: GROUP B | | *A: Let's discuss it* | *G2* |
| 3 | | **A: I believe that one entity is (supermarket) VELO** | | *A: I believe the entity VELO... ...and the entity ABC are part of the requested model* | *G2* |
| 4 | | **A: (cont.) and another one (the firm) ABC** | | *... I would like to know your opinion on this.* | *G2* |
| 5 | | **A: (cont.) do you agree?** | | *...While you are thinking I* | *G2* |
| 6 | 12:43:14 | Added rectangle object | | *will show you what I mean* | *G2* |
| 7 | | | **B: What their attributes will be?** | *B: I do not believe that VELO and ABC are entities. There is no reference in the handouts on any attributes of them* | *G2* |
| 8 | | | **B: I do not agree** | *...so I do not agree with your statement* | *G2* |
| 9 | 12:43:29 | named object "" | | *A: I should build some more entities while we are talking* | *G2* |

(Continued.)

| No | Time-line | Partner A (Actions and messages) | Partner B (Actions and messages) | Equivalent communication act | Goal |
|---|---|---|---|---|---|
| **10** | | **A: What entities do we have then?** | | *A: If you do not agree, can you suggest some entities yourself* | *G2* |
| **11** | | | **B: One entity is the STOREHOUSES** | *B: One entity is the STOREHOUSES* | *G2* |
| **12** | **12:44:26** | creation of few un-named objects | | | |
| **13** | | | **B: Every Storehouse is an instance of this entity** | *B: I believe that every Storehouse is an instance of this entity* | *G2* |
| **14** | **12:44:54** | Added rectangle object – named object VELO | | *A: I think you are right about STOREHOUSES, but I still think that the entities I have suggested are correct, so entities are VELO, ABC, STOREHOUSES...* | *G2* |
| **15** | **12:45:07** | Added rectangle object – named object ABC | | | |
| **16** | **12:45:48** | Added rectangle object – named object TRUCKS | | *...also the TRUCKS. This is a new entity that I propose* | *G2* |
| **17** | **12:45:58** | Added rectangle object – named object STOREHOUSES | | | |
| **18** | | | **B: Could you tell me what are you doing?** | *B: (I think you are a bit confused). Why have you put everything in the shared space?* | *G2* |
| **19** | | **A: There is a disagreement at this end** | | *A: We do not agree between us about VELO and ABC as entities* | *G2* |
| **20** | | **A: Entities VELO and ABC?** | | | |
| **21** | | | **B: what do you put at the storehouses?** | *B: If you have an entity VELO and an entity STOREHOUSE what attributes do you assign to one and the other? ...also STORES are a separate entity* | *G2* |
| **22** | | | **B (cont.): we should also create a STORES entity** | | *G2* |
| **23** | | **A: I believe the Storehouses is a weak entity** | | *A: OK You convinced me about STOREHOUSES, but I will like to see VELO as an entity, so it is a weak entity dependent on VELO* | *G2* |
| **24** | | | **B: That's right** | *B: OK I will accept this...* | *G2* |
| **25** | | | **B: (cont.) and another one is the STORES** | *B: Also the STORES which I proposed earlier are also dependent on VELO* | *G2* |

(Continued.)

| No | Time-line | Partner A (Actions and messages) | Partner B (Actions and messages) | Equivalent communication act | Goal |
|---|---|---|---|---|---|
| **26** | **12:50:24** | Insert Map at object VELO (Level 1) | | *A: OK since we agree I will go on inserting the attributes* | *G4 (A)* |
| **27** | **12:50:26** | Level Up (Current Level 0) | | *of VELO in the next level* | *G4 (A)* |
| **28** | **12:50:40** | Show Map VELO (Level 1) | | *... I first experiment with moving up and down the multilevel model...* | |
| **29** | **12:50:50** | Added Rectangle object – name object STORES (Level 1) | | *And I will add STORES and STOREHOUSES as attributes...* | *G4 (A)* |
| **30** | | | **B: What are you doing?** | *B: I do not think that what you are just doing is in line with our previous discussion, so can you explain yourself?* | *conflict* |
| **31** | **12:50:58** | name object STOREHOUSES (Level 1) | | *... (I should complete what I am doing first before answering any questions)* | *G4 (A)* |
| **32** | | **A: Supermarket VELO has as attributes** | | *A: Now then, I believe that the supermarket VELO has as attributes...* | *G4 (A)* |
| **33** | | **A: the STORES and STOREHOUSES** | | *The STORES and STOREHOUSES* | *G4 (A)* |
| **34** | | | **B: VELO is not an entity** | *B: Now that I see it, I do not think that VELO is an entity at all.* | *G2* |
| **35** | **12:51:50** | Level Up (Current Level 0) | | *A (while we are negotiating I will try to built some attributes* | *G4 (A)* |
| **36** | **12:51:53** | Rename object “” | | *for entity ABC...* | *G4 (A)* |
| **37** | **12:51:55** | Insert Map at object ABC (Level 1) | | *... this is a different goal than the one we are just pursuing,* | *G4(A)* |
| **38** | **12:51:57** | Added Rectangle object – rename object “” (Level 1) | | *but if I manage to find some attributes I will convince you* | *G4 (A)* |
| **39** | **12:52:01** | Level Up (Current Level 0) | | *about the entity itself* | *G4 (A)* |
| **40** | **12:52:42** | | **B: (I suggest the following) entities:** | *B: I am not at all sure about what you are suggesting.* | *G2 (B)* |
| **41** | | | **B (cont.): STOREHOUSES** | *Quite the opposite, ABC and VELO I think are out. To the* | *G2 (B)* |
| **42** | | | **B (cont.): STORES** | *entities STOREHOUSES,* | *G2 (B)* |
| **43** | | | **B (cont.): DELIVERIES** | *STORES and TRUCKS that* | *G2 (B)* |
| **44** | | | **B (cont.): TRUCKS** | *we have already we should* | *G2 (B)* |
| **45** | | | **B (cont.): any comments?** | *add the entity DELIVERY* | *G2 (B)* |
| **46** | | **A: You mean DELIVERIES are entities?** | | *A: I do not see the DELIVERIES as entities* | *G2* |
| **47** | | | **B: Yes they have their own attributes** | *B: Yes they have their own attributes, you can see in the* | *G2* |
| **48** | | | **B (cont.): look into the handouts** | *handouts* | *G2* |

(Continued.)

| No | Time-line | Partner A (Actions and messages) | Partner B (Actions and messages) | Equivalent communication act | Goal |
|---|---|---|---|---|---|
| **49** | **12:55:02** | Added Rectangle object – name object STORES | | *A: (perhaps after looking in the handouts) OK I add the* | *G2* |
| **50** | **12:55:17** | Added Rectangle object – name object DELIVERIES | | *STORES and the DELIVERIES And I will get rid of the VELO, ABC, etc.* | *G2* |
| **51** | | (started deleting superfluous entities) | | | *G2* |
| **52** | **12:55:40** | | **B: I think each DELIVERY is linked to** | *B: OK I agree with the entities. Now I suggest we* | *G3 (B)* |
| **53** | | | **B: (cont.) a STORE, a STOREHOUSE and a VAN** | *move to the task of identifying the links…* | |