V. KOMIS, N. AVOURIS, C. FIDAS

A STUDY ON HETEROGENEITY DURING REAL-TIME COLLABORATIVE PROBLEM SOLVING

Abstract. This paper discusses the effect of learning material heterogeneity on real-time computer-supported collaborative problem solving. A study has been contacted in the frame of an authentic educational activity in a Greek secondary school. The students involved were provided with sets of primitive resources of varying degrees of heterogeneity to be used during collaborative modelling activities. Analysis of students peer interaction and produced solutions revealed that, contrary to our expectations, the group with heterogeneous resources produced solutions of similar quality to that of the reference group that possessed homogeneous learning material, while they were more active, exchanged more messages, were involved in deeper discussions and overall collaborated in great extend. The reported findings can have implications in the design of education scenarios involving distance real-time collaboration.

1. INTRODUCTION

In the frame of computer-supported collaboration research, special interest has been shown on the investigation of the effectiveness of CSCL environments under various conditions. This often involves design of experimental environments, which provide learning resources and in particular primitive entities that can be used in the process. In most cases these primitive entities belong to a pre-determined closed set. Examples of these primitives can be libraries of abstract objects, like rectangles, ellipses, squares, different statement types, etc., as it is the case for Belvedere (Suthers & Jones, 1997), COLER (Constantino & Suthers, 2001), C-CHENE (Baker & Lund, 1997), Modeler Tool (Koch, Schlichter and Trondle, 2001). These can take special meaning for the students during problem solving. So common understanding among collaborators is based on the existence of these common basic primitives and the solution is built using these available shared resources.

This is one of the mechanisms provided for scaffolding the collaborative activity. These common primitives are the items about which the users argue and discuss before converging to a commonly acceptable solution (Suthers, 2000). According to Stahl (2002) the students can start their argumentation only after they have built a common understanding of their meaning and use it in the modelling activity.

However this "closed environment" assumption is not always true. Today collaborative problem solving activity can take place within open systems, which permit additional resources to be built or sought by the students themselves. In addition, pedagogical motivations often encourage this "open" approach. As a consequence the building blocks are not shared among all the partners who therefore need to negotiate the available resources before even start getting engaged in problem solving. The collaborators search for primitive entities in a wider space like the Internet, or even build new entities themselves during the process. This is the case of ModelsCreator 3.0 (MC3) (Fidas, Komis, Avouris, Dimitracopoulou, 2002)

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the environment used in our study. MC3 permits synchronous distance collaboration for building and exploring models made out of primitive entities. These entities represent concepts with properties and visual behaviour. In this environment a student before entering in a specific collaborative modelling session may search for or build individually a new set of primitive elements to which meaning can be assigned. The student is provided with an adequate editor that permits creation of these new entities or modification of existing ones. As a consequence, collaborating students may find themselves in possession of heterogeneous sets of primitive objects. Even if the collaborating partners share a problem definition and given data set, one or more of the partners may have access to additional basic constructs or compound primitives, making the process of grounding of interaction and common understanding particularly complex.

In the reported here research we have attempted to investigate this aspect of collaborative learning by studying the role of not-shared primitive constructs in collaborative modelling activities. Building a common understanding in such a case is a difficult process.

In particular, during the reported study we examined how heterogeneous primitives affect synchronous collaboration at a distance. The main premise has been to investigate if the heterogeneity of resources have any effect on collaboration, since the students need in this case to seek and agree on a common set of primitives before building a solution, while there has been also a concern that the lack of a common set of primitive resources can create misunderstandings among the students.

In order to achieve these objectives we set up an experiment involving collaborative problem solving of pairs of students at a distance, when the partners possessed sets of building blocks of the solution of varying degrees of heterogeneity.

2. SETTING DEGREES OF HETEROGENEITY

2.1. Context of the study

The reported study took place in the frame of educational activity of a Greek Technical Lyceum (ages 15-16). Twenty students and their tutor took part in the experiment that took place, in the context of a class on "Internet Technology". The class was divided in two groups (A and B), each one of them made of five (5) pairs of students: A_i, i=1,5 and B_j, j=1,5. Special attention was put on selecting the pairs of students in such way that their cognitive and subject matter skills to be of similar level. The members of each pair collaborated using the MC3 environment in order to provide a solution to a given problem, which is described in more detail in the following. The physical location of the students in the lab was such that the collaboration within each pair was effected exclusively through the provided tools, thus simulating distance collaboration. The pairs of group A, which was used as a control group, shared a common set of primitive entities, while those of group B possessed heterogeneous entity sets. The students were given an activity sheet and instructions on the problem solving strategy to be followed during the provided time (50-55 min.). The problem that was given to each pair was to form an offer for a package holiday, pretending they were two clerks of a travel agency, working at a distance. The students were provided with primitive entities representing key concepts; these were the holiday budget, the cost of lodging, the duration of holidays, the cost per person, the number of travellers and the means of transport. These entities could be inter-related in the activity space in order to build a model of the holiday offer, on which various if-then-else scenarios could be tried. The tutor did not intervene during the process.

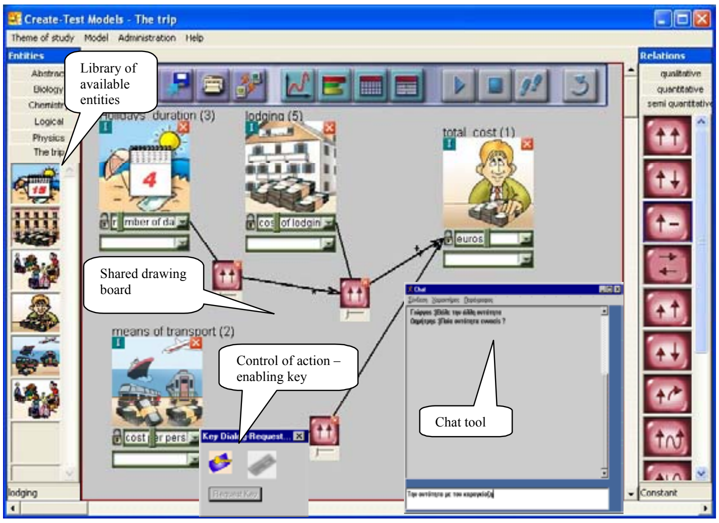

Figure 1: The ModelsCreator v. 3.0 environment during model building

2.2. The Models Creator 3.0 learning environment

During this study the ModelsCreator 3.0 (MC3) (Fidas et al., 2002) collaborative modelling environment was used. This is an evolution of Models Creator (MC) (Komis, et al. 2001), an earlier prototype supporting modeling activities. MC3 is a modelling learning environment that facilitates building of various kinds of models, with special emphasis on semi-quantitative modelling. The structural elements of the MC3 models are the entities, the entities' properties and the relationships among entities. Entities are the objects or the concepts that constitute a model (such as man, tree, holidays etc.). Properties are intrinsic characteristics of the entities that change, rendering the model a dynamic behaviour. Relationships define the ways according to which the entities' properties change and affect each other. The user of MC3 can modify the primitive entities available. New entities can be defined using an entities editor or can be imported from the Internet or exchanged among users of MC3. This characteristic of MC3 makes it an open environment, in which the primitive modelling constructs can vary between different installations. MC3 puts great emphasis on visualization of the modelling entities. The standalone edition of MC (version MC 2.0) is freely available for experimental use, (see www.ModellingSpace.net). A new experimental version 3.0 (MC3) has been recently built to support synchronous and asynchronous collaboration at a distance. This version of the software has been used in our study. MC3 contains tools for exchange of text messages between collaborating partners and sharing of the common activity space, through a replicated architecture.

The shared Activity Space can become a drawing space of synchronous collaboration, in which one of the two collaborating partners can insert primary objects (entities and relations), through direct manipulation. When connection between two partners is established, a copy of the drawing board is build and maintained in both parts involved until the connection is terminated by one of them. This protocol is an essential part of the architecture, since it maintains clear semantics of actions and roles in the shared activity space. Peer support in this context takes place through exchanged chat messages between the students and through actions in the activity space.

2.3. Educational scenario

The scenario involved formulation of a package holiday offer by the students who were supposed to be clerks of a Travel Agency working at a distance. They had to negotiate on the main entities affecting the characteristics of the offer using the provided tools (chat tool and collaborative modelling tool)

The activity sheet that was given to the students explicitly requested from them to discuss the main entities that affect the offer, using the chat tool, and to define their relation (total cost, destination, duration, cost of lodging etc.) Subsequently, the students had to build jointly a model, which would represent their offer. Each pair of distant students produced a separate solution to the problem. The setting of the experiment and the tools did not seem to cause any particular usability problems to this group of students, who were quickly acquainted with the tools and used them efficiently, this was attributed to the fact that they had information technology as the main subject of their studies. However the quality of the produced solutions to the problem was not particularly high, as there seemed to exist lack of understanding of the background domains involved in the given problem (tourist industry, budgeting etc.). In particular, the solutions produced were evaluated in a 10 points scale, according to which the solutions of group A took the following marks: A1=3.0, A2=3.0, A3=2.5, A4=4.5 while those of group B were B1=3.0, B2=4.0, B3=2.0, B4=4.0, B5=3.0. The mean score per group was 3.2 for both groups. So a first finding was that the heterogeneity of the primitive resources did not have any effect on the quality of the produced solutions. In the next section we proceed with analysis of the collaborative problem solving activity that produced these solutions.

3. ANALYSIS OF COLLABORATIVE PROBLEM SOLVING

The findings of the study, discussed in this section are based on logfiles of activity which include exchanged dialogue messages and operations on the common activity space, in chronological order, collected during the field experiment. Analysis of these data is based on the OCAF model of analysis (Avouris et al., 2003), as well as quantitative and qualitative analysis of interaction. In the following section we provide a brief introduction to the main principles of the methodology used.

3.1 Methodology of analysis

The Object Oriented Collaborative Analysis Framework (OCAF) (Avouris et al., 2003), is particularly suitable for analysis of collaborative problem solving activity, which involves interleaving of actions and dialogue. This framework puts emphasis on the objects of the jointly developed solution. Every object is assigned its own history of events (actions and messages) related to its existence.
The history of each one of these objects is a sequence of events that refer to an actor and an action according to the functional types, shown in Table 1. An example of an object history is: E(budget)= X_P,X_I,X_P,X_P,Y_P,Y_P,X_R, indicating that agents X and Y interacted in relation to entity *budget* taking the assigned functional roles.

Table 1: OCAF analysis model: the main functional types

ID	**Functional Role**	**Derived from :**	**Example**
I =	Insertion of the item in the shared space	*action analysis*	*Action:* 'Insertion' of Entity "X"
P=	Proposal of an item or proposal of a state of an item	*dialogue analysis*	*Message:* "I believe that one entity is the "A" or "let us put the value of entity Y to state *locked*"
C=	Contestation of the proposal	*dialogue analysis*	*Message: I think that this should be linked to the entity B by the "analogue to" relation*
R=	Rejection / refutation of the proposal	*action and/or dialogue analysis*	*Message:* "What their attributes will be ? I don't agree". Or *Action:* 'Delete' Entity "X"
X=	Acknowledgement/ acceptance of the proposal	*Action and / or dialogue analysis*	*Message:* "That's right" *or* *Action: Insertion of* a proposed entity
T=	Test/Verify using tools or other means of an object or a construct (model)	*actions & dialogue analyses*	*Message:* Let us run this model to observe this part of the model behavior *Action:* Activate 'Graph Tool' , or 'Barchart Tool''

3.2 Quantitative analysis of dialogues and actions

Comparison of the overall activity of the pairs of Group A and Group B has revealed that partners of group A produced as an average 16,5 events per pair (actions and exchanged text messages) while partners of group B 19,9 events. So overall group B was more active. Breakdown of this activity according to the OCAF functional roles indicated that the main difference is contributed to *Proposals* (1.5 more actions on average per pair), *Rejections* (0.8 more actions) and *Testing* (0,8 more actions), while for the rest of the functional roles the difference is not significant. The unpaired two-tailed t test has confirmed statistically significant difference of the two values for Proposals ($t=2.31$, $p=0.049$, the 95%, confidence intervals 0.011 to 5.989), while the difference is not statistically significant for the other types of events. The operator *Insert* is of the same level for both groups, since the produced solutions where of similar complexity as discussed in the evaluation of the solutions.

Rejections (R) are higher in group B (not statistically significant difference though), since in group B more proposals (P) were made. The Propose (P) role occurred more often in group B than in group A. According to Avouris et al. (2003), this functional role is a strong indication of ownership of entities and relations as well as strong indication of participation in collaboration.
It has been observed that the pairs of group B took the T (test/verify) functional role more actively. This can be related to the fact that in this group there were more proposals, which needed to be evaluated and rejected after testing and verification, using the provided tools (i.e. the "run the model" tool, manipulating the values for entities' properties). The conclusion of this analysis is therefore that group B is more active and takes roles that indicate collaborative activity, more often than group A. In the following a more detailed analysis of this activity is performed.

3.3 Analysis of communication

An additional point of view concerns the textual interaction that took place during problem solving, following a methodology also used by Komis et al., (2002). As expected, communication between members of group B was more intense. The overall number of exchanged messages was 150 between partners of group A and 175 between partners of group B. While there is no statistically significant difference between the two sets of values (t=1,26, P=0,24253, the 95%, 2,306) the mean value of exchanged messages for group B is higher than that of group A. This applies to all major categories of messages.
In particular, exchanged messages were classified as: *strategy* related or control messages; *task* related : task A (compilation of offer and discussion of entities) and task B (investigation of relations and model building and testing); related to the *usage of tools*; off-task or *social*.
In all categories, except the *tools*, group B exchanged more messages, as shown in figure 2. While in the difference is not statistically significant, the trend indicates that in group B interaction related to problem-solving tasks was more intense, while those related to the modelling task have increased as a percentage of exchanged messages even within the group itself (21% in group B against 17% in group A).

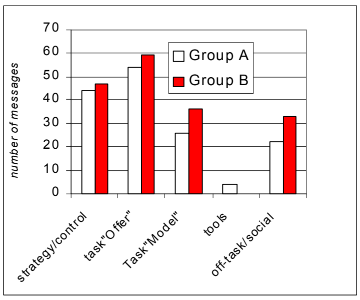

Figure 2: Breakdown of messages per category

Finally it is worth studying the content of exchanged messages, in order to establish the degree of collaboration. In particular the interaction related to strategy in group B is much more rich. In group A, messages of this category, seem to refer mostly to the contents of the holiday offer, and key exchange, while in group B strategy-related interaction is mostly related to the modelling task and thus involves deep interaction on the domain. For instance in pair B2 student 1 requests from 2 to send him/her all the entities, which is accepted by partner 2. In pair B1 the two partners discuss first verbally the content of their libraries and subsequently they negotiate on their activity, e.g. event 73, partner (1) says "you add the property of entity holiday duration first and then pass me the key so that I relate it to holiday budget".

3.4 Analysis of entities history

The primitive entities used in problem solving were six (6). They can be distinguished in two categories. The two entities that were shared by the partners of all pairs (called shared entities) and the four entities that were split between the two partners in the pairs of group B (called not shared entities). In this section we examine the history of all entities that participated in the produced solutions. In particular, one aspect worth investigation is whether the not shared entities carry longer history in pairs of group B than in pairs of group A where they were shared. For all pairs we have the length of entities history, derived from the OCAF model. From this analysis it was deduced that the not shared entities were produced by 4,5 events per entity for group B, while there were 3,6 events per entity for the same entities in group A, where they where shared among the partners.
The average history length per entity for the shared entities (Cost per traveller and Number of travellers) for group A was 3,2, while for group B it was 3,0, i.e. there is no significant difference in the two groups activity related to them, while it seems that group B focused more their activity in the not-shared entities.

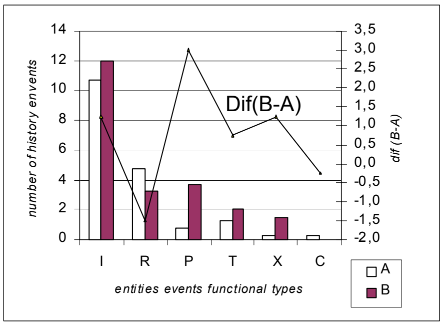

Figure 3. Number of events for not shared entities

Further analysis of the difference in the behaviour of the two groups, involves the detailed analysis of types of actions related to each entity that participated in the solution of each group. We performed this analysis separately for the shared and the non-shared entities. It was found that there is not significant difference for the shared entities between actions of group A and B, while for the not shared entities, it appears that type P actions (proposals) appear to differ significantly, a similar finding to that of section 3.2 that concerned the overall activity. So the proposals seem to be the actions that contribute mostly to the observed (however not statistically significant due to the small sample) difference in the entities-related activity as well as the overall activity between the two groups. This is shown in Figure 3, which depicts graphically the number of history events per entity for the not shared entities, broken down according to the OCAF functional roles.

3.5 Entities ownership analysis

An additional result of entities analysis concerns the ownership of parts of the solution. The ownership of entities establishes which partners participate actively in introduction of an entity in a model. This is a key notion in the analysis framework used. Any actor that participates in the history of a part of the solution according to OCAF, either by proposing or contesting its creation is defined as "owner" of this part of the solution. If an entity has just one owner, this is an indication that there has been no collaboration at the level of this entity, while it is a good indication of collaboration if both participants are the owners. It is obvious that there can be various collaboration schemes used by the students, i.e. one could be a "divide and conquer" strategy, which means that the partners decide explicitly or implicitly to build separate parts of the model and not interfere with each other's activity or another collaboration scheme can involve a more synergistic strategy when both discuss and argue for the constituent parts of the model. This collaboration can be measured through the entities ownership attribute.

Table 2: Ownership of Group A and Group B entities

Group A		
Pair	**Single ownership entities**	**Joined ownership entities**
A1	3	1
A2	1	1
A3	1	2
A4	1	2
A5	1	2
Total	**7**	**8**
%	**47%**	**53%**

Group B		
Pair	**Single ownership entities**	**Joined ownership entities**
B1	0	3
B2	1	3
B3	1	2
B4	1	2
B5	2	1
Total	**5**	**11**
%	**31%**	**69%**

In Table 2 the ownership of entities is shown. From this table it appears that in group A just half of the entities are of joined ownership, while in group B they are more than two thirds. It seems from these tables that in group B more often the entities that take part in the solution of the problem are not a matter of activity of just the original owner and proposer, instead they become subjects of discussion and collaboration. In other words, sectionalisation of the primitive entities among partners has not created, as one might expect, a more sectionalised solution, but rather contributes to joint solutions of the problem and therefore to more collaboration.

4. CONCLUSIONS

This study focused on the effect of heterogeneous sets of primitive entities on synchronous collaborative problem solving. In particular we studied the effect of not shared entities on collaborative modelling.

A prime observation is that the produced solutions by the two groups A and B were of similar quality. However, some distinct differences were observed between them. Group B was overall more active in terms of actions and dialogue. In addition it was observed that the pairs of group B made twice as many proposals concerning parts of the solution (2,9 against 1,4 proposals per partner of group A), an indication of stronger collaboration. Furthermore, by studying the history of the solution components we found that in group B considerably more components were owned by both partners (69%) than in group A (53%). From these observations, we concluded that in group B there was more discussion and collaboration relating to the constituent parts of the solution. This was mainly due to the not-shared entities, which were more the subject of discussion and negotiation than the common ones. It seems that the existence of not shared entities instead of creating additional difficulty to collaborating partners, as expected, was a reason for more involvement and deeper discussions, without any deterioration of the quality of the produced solutions.

Analysis of the problem-solving strategies used by the two groups revealed that while group A started straight away with problem solving, the pairs of group B first searched and discussed available entities and the concepts that they represent, which helped them build a more collaborative attitude.

Taking into account the importance of the primitive entities in collaborative problem solving, as these are the main constructs that support common understanding and building of a shared meaning (Baker et al. 1999, Seitamaa-Hakkarainen, Raunio, Raami, Muukonen & Hakkarainen, 2001), the findings of this study are of more general value. Open systems are inevitably characterized by heterogeneity of primary resources. One might expect that this "openness" can be a source of uncertainty, inhibiting effective collaboration. However the findings of this study reveal that there might be some positive aspects relating to the deeper engagement of partners who attempt to work together towards a common understanding. It should be observed that in the reported experiment the students shared a common cultural, cognitive and social context, as members of the same class. Luck of this condition could have inhibited further sharing of understanding in relation to the heterogeneous entities, a premise requiring further validation.

In conclusion, open collaboration environments, like MC3, can eventually provoke more semantically rich patterns of interaction. The introduced uncertainty by the existence of heterogeneous entity libraries has been overcome by closer collaboration of the partners, which seemed to have produced as good solutions, following different strategies.

11. NOTES

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Affiliations

Vassilis Komis is with the Department of Early Childhood Education, Nikolaos Avouris and Christos Fidas are with the ECE Department, Human-Computer Interaction Group of the University of Patras, GR-26500 Rio Patras, Greece