OCAF: An Object-oriented Model of Analysis of Collaborative Problem Solving

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ABSTRACT

Computer-supported collaborative problem solving requires new methodological approaches of interaction and problem solving analysis. Usually analysis of collaborative problem solving situations is done through discourse analysis or interaction analysis, where in the center of attention are the actors involved (students, tutors etc.). An alternative framework, called "Object-oriented Collaboration Analysis Framework (OCAF)" is presented here, according to which the objects of the collaboratively developed solution become the center of attention and are studied as entities that carry their own history. This approach produces a view of the process, according to which the solution is made of structural components that are 'owned' by actors who have contributed in various degrees to their development. OCAF is based on both actions and dialogues of actors, providing qualitative as well as quantitative indicators of collaboration and solution quality. The paper presents first the framework notation. Examples of its use in analysis of distance groups and face-to-face collaborative activities are provided next, followed by the dimensions of the framework supported analysis for teachers and researchers. Web-based tools supporting the OCAF approach are also presented.

Keywords

Collaborative problem solving analysis, face-to-face collaboration analysis, dialogue-action analysis, web-based analysis tools

INTRODUCTION

The methodological issues of collaboration analysis are important to the effectiveness of the collaborative learning process, the designation of appropriate learning activities and settings, as well as the design of collaborative technology-based learning environments. Analysis of collaborative problem-solving situations is usually done through discourse analysis (Baker *et al.*, 1999), task analysis interaction analysis, or even a combination of methods (Komis, Avouris & Fidas, 2001), with the objective to evaluate the situation, the learning process and often the tools used. A number of different approaches have been developed for the analysis of collaborative activities in different mediums and environments. Some of them are focused on problem solving strategies or on plan recognition (Hoppe & Ploetzner, 1999), others on the evaluation of partners' involvement (Simmof, 1999), or on the process of mutual understanding and the learning effects (Baker *et al.*, 1999). There are approaches of analysis implemented after the interaction and others that are applicable during the evolution of the collaborative process, thus providing assistance tools that are able to evaluate personal contribution and visualise collaboration patterns (Simmof, 1999).

It seems that in this research field, collaboration analysis is mainly based on analysis of naturally occurring dialogue, due to a remaining dominant psychological interest in answering general questions related to understanding collaborative learning. It is interesting to examine the main analysis approaches, in the specific category of technology-based collaborative problem solving systems related to 'diagrammatic solutions', a category where the actions of collaborative partners are of main importance. This is due to the fact that these actions reveal information on the quality of involved concepts and strategies of pupils in a learning process. In this category, representative research and analysis approaches are: The networked collaborative concept mapping system produced by CRESST (Chung *et al.*, 1999), the CardDalis prototype (Muehlenbrock & Hoppe, 1999) interesting in terms of group action-driven interaction analysis, the research related to the C-CHENE system (Baker *et al.*, 1999), designed to support dyads of students collaborating in the construction of diagrams of energy chains, and the BELVEDERE v.2, a networked software system, allowing students to collaborate during scientific inquiries (Suthers, 1999). Dominant approach of analysis in relevant experimentations, is the dialogue-oriented one. Even if in some cases, like the COLER system experimentations (Suthers & Hundhausen, 2001), common transcripts of dialogues and actions are reported, a well coordinated analysis related to the components of the reported solutions is not included. Moreover, in all these analysis techniques the center of attention are usually the actors (students, teachers etc.) and the dialogues, while the developed objects often enter the scene only as items on which operations are effected and as subjects of discussion.

An alternative and complementary framework of analysis is presented here, according to which the objects of the solution, that is the objects that exist in the 'micro world', become the center of attention and are studied as entities that carry their own history and are acted upon by their owners. This perspective produces a new view of the process, according to which the solution is made up of structural components that are "owned" by actors who have contributed in various degrees to the produced solution. This view of the world, which is a reversed view of the one we usually build of the problem solving process, can be useful, as it reveals the contribution of the various actors in parts of the solution, identifies areas of intense collaboration in relation to the final solution and can relate easily to other analysis frameworks like interaction analysis.

According to this view an operational framework of analysis and evaluation of collaborative problem solving has been defined called 'Object-oriented Collaboration Analysis Framework" (OCAF), also described in Avouris *et al.* (2001). OCAF's corresponding analytic model identifies patterns of interaction and relates them to objects of the shared solution. The model provides a new way of representing collaborative problem solving activity, taking into account both actions and dialogues of partners and supports qualitative and quantitative representations that can be used as meta-analysis and evaluation tools. The framework has been used for the analysis of various kinds of collaborative problem solving environments based on jointly developed diagrammatic 'solutions', made of well distinguished objects, such as concept maps, entity-relationship diagrams, diagrams of specific modeling formalisms, architectural diagrams, etc. It is shown that this approach can be applied both in synchronous distance-collaboration environments (dialogue via written messages) and in co-located group collaboration when a more oral-dialogue oriented collaboration occurs.

The proposed analysis framework proposes a model that can be generated and further processed by adequate tools, attached to a collaboration support environment. These tools could be used not only by researchers but also by teachers managing on-line distance collaborative problem solving or by students, in an appropriate form, as a meta-cognitive or collaboration meta-analysis tool, helping them self-regulate their actions and their involvement.

Most of the existing collaboration systems present limitations when used by young students in real school settings. Some of the limitations are attributed to the fact that the teacher who is in charge of several students, fails to interpret the enormous number of complex interactions that can take place simultaneously. Acknowledging this limitation, researchers have started to work on addressing this problem. Systems that aggregate the interaction data of logfiles into a set of high-level indicators and present them to the participants or the teacher have been proposed. From these systems, we could distinguish three main categories: (a) Systems that present or visualize indicators concerning exchanged patterns in a discussion. The system proposed by Simmof (1999) visualizes in an innovative way discussion threads with nested boxes exploiting quantitative information on participation rates in exchanged messages. In MarCo, a dialogue oriented system (Tedesco & Self 2000), a mechanism detects disagreements and conflicts between users' beliefs or intentions, on the basis of selected dialogue acts. (b) Tools based on qualitative analysis of members actions, deriving higher order descriptions of group activities, such as the CardDalis system (Muehlenbrock & Hoppe 1999) were applied in the low level conceptual task of puzzle resolution. FACT (More & Moriyon 2001) is another framework that produces tree-like histories, related to actions. (c) Systems that analyse messages and actions such as the system under development by Jermann et al. (2001) that displays separate indicators of participation rates on messages and others on actions. Other systems, such as EPSILON (Soller & Lesgold, 2000) and COLER (Constantino-Consalez & Suthers, 2001), analyse data from actions and messages and monitor directly group members by appropriate messages, without presenting the derived information to users (students or teachers).

In order to develop effective analysis frameworks and tools for collaborative problem solving, the research community needs to investigate some key questions:
How to coordinate the analysis of actions and dialogues?

How to inter-relate collaboration features with problem solving content and process?

How to go beyond simple quantitative indicators (e.g. participation rates) to more sophisticated ones, such as role distribution that involve analysis of semantic aspects of interaction?

- How to provide a rich variety of analysis output, to assist facilitators or experienced learners?

This paper makes an attempt to explore some of the above issues. First the OCAF framework and its model in textual and diagrammatic form are presented. Subsequently, some analysis examples are presented, through two different case studies, involving a synchronous distance-collaboration environment and a co-located group collaboration. The analysis dimensions of these cases are discussed in view of OCAF applicability and usefulness in research and teaching issues. The main functionality of a tool supporting the OCAF framework is also presented.

THE OCAF FRAMEWORK

The proposed framework is based on two basic considerations, one related to the *object oriented view* of collaborating actors' roles and contributions and the other to the *unified analysis of dialogues and actions on objects*.

a) The diagrammatic solution of the problem is a representation of the shared effort of the involved partners as well as of their shared memory. In OCAF we shift the center of attention on these objects of the solution. That implies that these objects, constitutive of the solution, are studied as entities that carry their own history and are acted upon by their owners (the actors involved in their conception, creation, modification and inter-relation in the specific diagrammatic solution built by them). This perspective produces a new view of the process, according to which the solution is made up from structural components that are "owned" by actors who have contributed in various degrees to the produced solution. This "object oriented view" focuses on the ownership of the constitutive objects of the solution, covering also parts of the solution that have not been completed or have been rejected in the process.

b) Previous research has shown (Baker *et al*., 1999) that mutual understanding among the collaborative agents takes place via a combination of perception of graphical action and communication. Furthermore, depending on the provided tools facilitating dialogue, the collaboration mode can vary from a more action-dominant mode to a more discussion-based mode. For these reasons, it is argued that there is a need to apply a unified analysis and interpretation of both dialogue and actions related to the solution objects, in order to analyze and evaluate collaborative activities in diagrammatic problem solution.

From the resulting framework of analysis, a model M of the solution is defined, conceived in this context, as a formal model, that can be used to analyze or reconstruct certain aspects of both actions and dialogues occurring in the problem-solving group. This model of ownership of the solution is based on the notion of ownership of the components of the diagrammatic solution. Such a diagram in many cases is made of objects (entities) that are shown in the diagram in abstract or pictorial form. These can be related through relationships often shown or implied in the solution. The entities have attributes or properties that are associated to them. The entity/relationship/attribute constructs could be the basic objects that make a diagrammatic solution according to the proposed notation of the framework. The proposed model according to OCAF has been formalized in textual and diagrammatic form as follows:

Let a given Solution S of a problem X be: $S(X) = \{ E_i , R_j, A_m, \}$, Where E represent the node entities of the solution, (i=1, …, k) R the relationships connecting them (j=1,…,l) and A the attributes of the entities (m=1, …, n) that participate in the solution.

The model of the solution can be:

$$M(S)= \{ E_i \ * \tau i / P_i f_j, P_k f_l, \ldots R_j \ * \tau i / P_i f_j, P_k f_l, \ldots, \ A_m \ * \tau i / P_i f_j, P_k f_l, \ldots;$$

$$-E_i \ * \tau i / P_i f_j, P_k f_l, \ldots, -R_j \ * \tau i / P_i f_j, P_k f_l, \ldots, -A_m \ * \tau i / P_i f_j, P_k f_l, \ldots \}$$

Where: E, R, A, are the entities, relations and attributes that are part of the final solution, while with –E, -R, -A the items discussed during the problem solving process, but not appearing in the final solution, are shown. τ_i is an index of the item, as implied by its initial action of insertion or by its discussion in the timeline of the problem solving process.

To each item a sequence of P_i f_j is associated. Each P_i f_j represents the human agent Pi (e.g. a student, teacher or facilitator) participating in a direct or indirect way in the problem solving process and his/her functional role f_j related to the particular part of the solution.

The different functional roles f used in OCAF are described in Table 1. It should be noticed that two functional roles concern the initial proposition to insert the item (by action (I) or by dialogue (P)), while the others express the discussion on each item. Also testing of the proposed solution is done through argumentation (A) in the case of static-diagrammatic solutions, while testing can involve use of alternative representations and provided testing tools in case of development of dynamic models of the solution (T).

So for example: [E (Storehouse)]=A_P B_M A_I indicates that the entity Storehouse has been produced from interaction of Agents A and B. Agent A made the initial proposal (A_P), which was modified subsequently by Agent B (B_M), finally Agent A inserted the object in the shared Activity space (A_I), accepting the final solution.

It has to be noticed that the actors' functions in interaction have been defined as 'functional roles' of 'communicative acts'. Initially, the 'functional role', was a term used in dialogue analysis in linguistics (Moeschler, 1992), transferred in educational research (Sabah *et al.*, 1999) in the context of verbal dialogues. A 'communicative act' (Bunt, 1989; Baker & Lund, 1997; Burtin, Brna & Pilgington, 2000) was a term referred on both oral and written communication. In our context, the term of 'communicative act' refers not only on messages (written dialogues during collaboration by distance), and oral utterances (during face to face collaboration), but also on actions of collaborative agents, given that during a synchronous collaborative activity these actions have a strong communicative value. Consequently, in our context of computer-based collaborative problem solving, a functional role reports the purpose of a 'communicative act', from the point of view of its 'actor' or 'interlocutor', thus constituting an interpretation of the actors/interlocutors intention in communication.

ID	Functional Role	Derived from :	Example
I =	Insertion of the item in the shared space	*action analysis*	*Action:* 'Insertion' of Entity "Velo"
P=	Proposal of an item or proposal of a state of an item	*dialogue analysis*	*Message:* "I believe that one entity is the firm 'ABC'" or "let us put the value of entity flow 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 "Velo"
X=	Acknowledgement/ acceptance of the proposal	*Action and / or dialogue analysis*	*Message:* "That's right" *or* *Action: Insertion of* a proposed enitity
M=	Modification of the initial proposal	*action & dialogue analyses*	*Message:* I suggest we put the state to "unlock" *Action:* "Modify"
A=	Argumentation on proposal	*dialogue analysis*	*Message:* "I believe that I am right because this is …"
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''

Table 1. Unified "functional roles" definitions

An alternative, diagrammatic representation of the model involves association of the solution items to their history as shown in the figures of next section. The advantage of the textual representation is that it can be produced and processed by an adequate tool, while the diagrammatic representation is easier for the human to study. The two representations of the model are equivalent.

CASE STUDIES OF OCAF APPLICATION

In this section application of the OCAF framework is presented in two different collaborative problem solving settings. In the following typical extracts of analysis are included. Subsequently, a discussion on the analysis dimensions is provided.

Case A : Collaborative distance problem solving

The first case study involves use of Representation V.2. (Komis, Avouris & Fidas, 2001), a system for synchronous collaborative problem solving, expressed through semantic diagrams. The system supports the simultaneous development of these diagrams by partners situated at a distance, through the use of a shared 'Activity Space'.

The case study, discussed more extensively by Komis, Avouris & Fidas (2001), is taken place in the context of a University undergraduate course. The problem solving task involved the collaborative building of a data 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 to support the companies involved in scheduling their trucks and delivery of supplies. The students had to express the model as an entity-relationship (ER) diagram, a representation often used in data modeling.

The main objective of the experimentation was to study the degree of collaboration and the development of problem solving strategies. Main sources of data for our analysis have been the log files, which contain details of inter-group communication acts (chat messages) and shared activity space actions, as well as the produced ER diagrams of the students. An extract of a log file, as well as its interpretation in terms of OCAF functional roles is shown in Table 2.

Partner E (Actions & Messages)	*Partner F (Actions & Messages)*	*Functional roles*	τ_i
E: ... about the entities, strong entities are ABC and VELO		ABC : E_P VELO: E_P	1 2
	F: Yes and also TRUCKS, STOREHOUSES and STORES	ABC : F_A VELO: F_A TRUCK : F_P STOREHOUSE : F_P STORES : F_P	 3 4 5
E: Attributes of (supermarket) VELO are the STOREHOUSES and the STORES		VELO.STOREHOUSE : E_P VELO. STORES : E_P	6 7
	F: and attributes of ABC the TRUCKS	ABC.TRUCK : F_P	8
Added rectangle object			
	F: No they are not attributes they are weak entities	VELO.STOREHOUSE : F_C VELO. STORES : F_C STOREHOUSE : F_A STORES : F_A	
E: ...and for ABC the TRUCKS (are attributes) and we need to show the JOURNEYS somehow		ABC.TRUCK : E_X	
The rectangle object is named VELO		VELO : E_I	
	F: I cannot see what you are doing	(Control statement)	
Added object- named object ABC		ABC : E_I	
	Could you pass me the action key please?	(Control statement)	

Table 2. Extract of interaction between partners E and F, in case study A [τ_i = index of solution items]

An example of analysis of collaborative solution is presented here. The problem solving team studied in this section is made of students E-F. The produced solution by this group is modeled, according to the OCAF framework, as shown in Figure 1. The last five items of M_{EF} concern objects discussed during problem solving process but not reported in the final solution due to conflicts between collaborating agents or not completed negotiation. The same model is shown in diagrammatic form in the same figure

An*alysis supported by the model* : From this descriptive model, firstly, a qualitative analysis on the content of solution may concern the appropriateness and completeness of the proposed solution. So, regarding the 'objects' of the solution, a researcher or teacher, can identify that for instance the object 'relation *Storehouse owns Trucks'* is not correct, since such ownership is not included in the problem description: the correct relationship could have been *Trucks are loaded at Storehouses*. In parallel, regarding the 'object' history related to collaboration, one can observe that this relationship has not been subject of strong collaboration. Another important aspect to study in a solution process, is the parts of the solution that lead to conflicts and did not take part in the final solution. For instance Actor E proposed Store as an attribute of entity VELO that was abandoned in favor of inserting Store as a separate entity, a solution that is more appropriate for the specific problem.

The model, can also, support a global quantitative analysis orientated to the solution items: Number of items in the model = 20, Number of items discussed and not included in the final model = 5, Number of items of unresolved conflicts =4.

Concerning the collaborative history of the produced solution, we could firstly, examine the history of each object of the solution. A quantitative analysis oriented to interaction patterns can identify (10) different interaction patterns in the model. The items produced per interaction pattern are:F_I = 5 (item inserted by F implicitly accepted by E), F_{IM} = 4 (item inserted by F, subsequently modified by same actor), F_{PI} = 3 (item proposed by F and subsequently inserted by the same actor), E_P F_I = 2 (proposed by E and inserted by F), F_P E_C F_A F_I = 2 (item proposed by F, contested by E, acknowledged argument by F and finally inserted by F), E_P F_R = 2, E_P F_C = 2 (item proposed by E and proposal rejected or contested by F with no further discussion) while five more patterns occurred once.

M_{EF} = {
Entities= E (ABC) = 1/E_P, F_A, E_I
E (VELO) = 2/ E_P, F_A, E_I
E (TRUCK) = 3/F_P, F_I
E (STOREHOUSE) = 4/F_P E_C, F_A, F_I
E (STORE) = 5/F_P E_C, F_A, F_I
E(DELIVERY)= 11/ F_P, E_X, F_I
Relations= R (VELO-owns-SH) = 9/F_{PI}
R (VELO-owns-ST) = 10/F_{PI}
R(TRUCK-transports- DELIVERY)=17/
R(SH-are-suppplied-by-TR) = 18/ F_{IM}
R (ABC-owns-TR) = 25/ F_{PI}
R(ST-owns-SH) = 24/ E_P F_P F_I E_C
R (ABC-owns-TR) = 25/ F_{PI}
Attributes= A (DEL.id) = 13/F_{IM}
A (DEL.volume) = 14/F_{IM}
A (DEL.Weight) = 15/F_I
A (DEL.Destination) = 16/F_I
A (TR.Max_Weight) = 19/F_I
A (TR.id) = 21/E_P, F_I
A (TR.Journey_id) = 23/F_I
A (TR.volume) = 20F_{IM}
A (SH.id) = 24/F_I
Items not in the final solution
-R (SH-DEL) = 12/E_P, F_R,
-A(VELO.Storehouse)=6/ E_P, F_C
-A(VELO.Store)= 7/ E_P, F_C
-A(ABC.Truck)= 8/ F_P, E_X
-A (TR.max_journeys_per_week) = 22/E

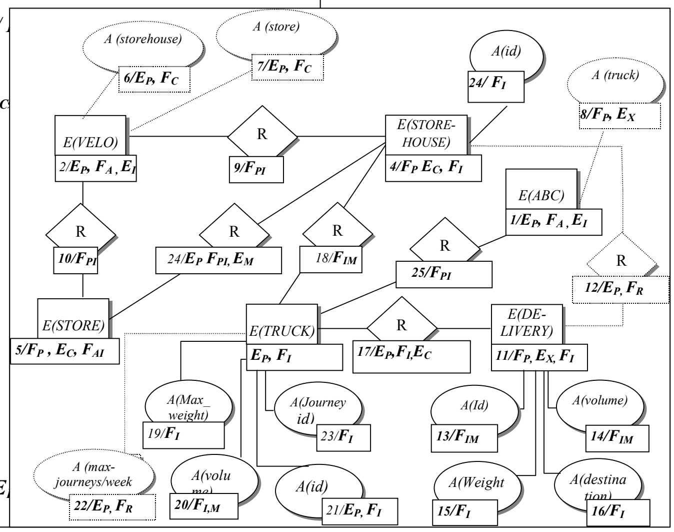

Figure 1. The solution expressed as OCAF model in (a)textual and (b) diagrammatic form

In relation to the *contributors* (in this example students E and F), one can determine that in this collaborating team, 25 items have been discussed, of which 12 have one owner and 13 two owners. The distribution of items proposals among the agents involved is: E=4 (20%), F=16 (80%), while 4 more items proposed by E and 1 proposed by F did not take part in the final solution. Such a distribution provides a strong indication of ownership and involvement.

Regarding the functional roles of each member, we can observe that member 'F' takes stronger action roles (e.g. I, M), while the observer (F) takes stronger verbal roles (e.g. P, C). Taking into account that the possession of the action-enabling key (permitting actions on the shared workspace to its owner) was 40% of the time for E and 60 % for F, one can infer the collaborative mode adopted by the group.

If the analysis is orientated towards examination of the '*subject'* of collaboration (where the group has focused), we could examine for instance the items of the solution in relation to ownership. In the presented example it is observed that the most important items of the developed solution (i.e. entities and relationships) are 8 of dual ownership (67%) and 4 of single ownership. In other words there has been stronger interaction in the process of creation of the backbone parts of the solution than the secondary parts (i.e. attributes).

Case B: Face to face collaborative problem solving

This case study involves a group of two 15 years old pupils (A and B) working as a group, in the presence of a facilitator F (a teacher-researcher). The experimentation took place in a laboratory. The students were asked to study a simple situation where a barrel can be filled by the water of a tap and build a model of the relations involved using MODELSCREATOR, a learning environment allowing creation and testing of models using pre-defined objects (Dimitracopoulou *et al.* 1999, Komis *et al.* 2001). The environment is a single-user tool, so one of the pupils is the operator of the tool, while the second pupil and the facilitator are observers. In order to build a solution, the pupils have to determine the relevant entities, their properties and the relations between them.

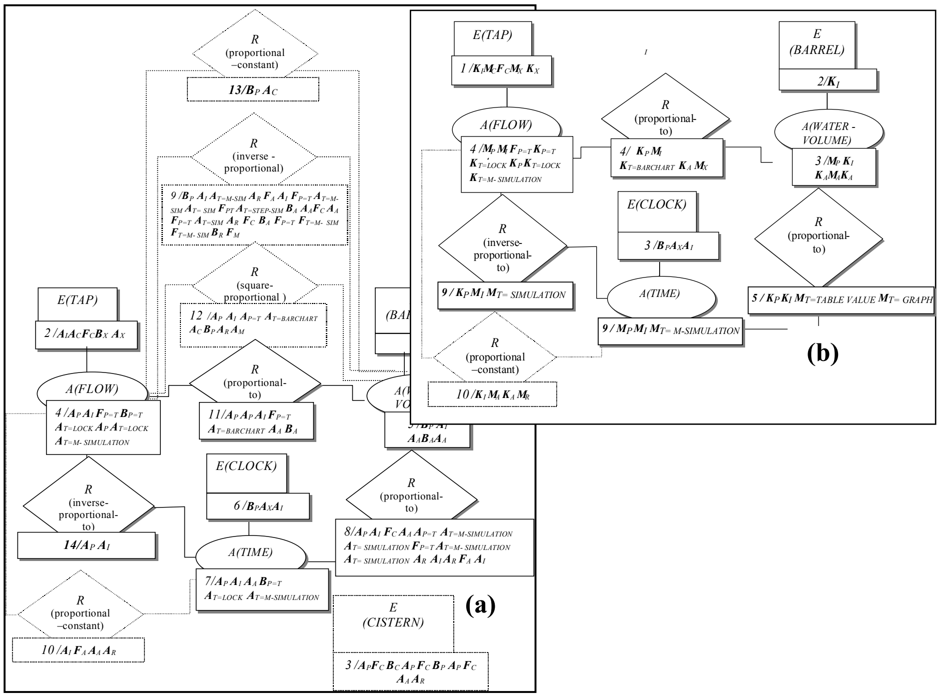

Figure 2, OCAF model for case study B. (a) students A,B, (b) students K,M

Typical models of this study are represented in diagrammatic form in figures 2a, 2b. From the model of figure (2a), an initial qualitative analysis, concerning the items themselves, can determine the appropriateness and completeness of the proposed solution. In order to interpret the conceptual difficulties of students or their mental models about implicated concepts, it is useful to consider a time dimension in the problem solving process, exploiting information derived from the order/index of items discussion (variable τ_i in OCAF model). For instance, the central entity CLOCK (τ_i=6) is inserted with some delay, due perhaps to the abstract nature of the concept of time. Additionally, it can be examined in which phases of the problem solving process the presence of facilitator (teacher) appears decisive. Examining the index of items discussion, in the presented example could be observed that the presence of F (facilitator) appears decisive in early stages (e.g. items 3, 8, 9), while the rejection of incorrect parts of the solution at a later stage (e.g. items 12 and 13) is done by the pupils themselves with no intervention of the facilitator.

Qualitative analysis oriented to the collaboration can be derived examining the history of collaboration of each solution 'object'. Observing the OCAF model, one can see that a number of solution items have been the subject of very strong exchanges. Additionally, a global quantitative analysis identifies, a wide variety of interaction patterns, with multiple exchanges. The rich interaction that took place is eventually due to the co-location of actors, the presence of the facilitator, and the existence of multiple tools that were used to validate alternative solutions.

If the analysis is oriented more specifically to each contributor (A, B and F), one can determine that in this collaborating team, 14 items have been discussed, of which 2 (14%) had one owner, 7 had two owners (50%) and 5 three owners (36%). From the objects of multiple ownership most of them have been assigned long interaction patterns, indication of strong interaction about the concepts involved.

Regarding the functional roles of each member contribution, we can account the distribution of items proposals among the agents participating that provides an indication of ownership and involvement. In this example, it was as following: A=10 (71%), B=4 (29%), F=0, ratio=2,5. It infers that actor A was mainly the operator ('Insertions' from A=15 and 'Insertions' from B=0, so this non-uniform distribution of ownership reflects these roles. Examining closer other 'roles', we can distinguish some problem solving strategies concerning the evaluation process of the produced solution: for instance, it can be observed that the pupils have tested parts of the solution (e.g. the relations) by using mostly manual simulation (Tool: M-SIMULATION) and did not validate the overall model (absence of tool 'RUN'), due perhaps to the simple structure of the developed model. Examining the indices of T(est) role, we have observed that only some of the available alternative representations (graphs, Bar charts, tables of values), have been used, and this in a limited degree.

From this analysis, one can deduce that most collaborative activity concerns the relationships (R). The objects themselves are inserted without many objections and therefore they do not become objects of discussion. Another observation on the density of collaboration is that there is a lot of interaction on objects not inserted in the model (e.g. relationship inverse-proportional between water-volume and tap-flow and on entity Cistern, see figure 2a).

The above analysis is focused on the exploitation of OCAF model's information related to a specific solution. Researchers and teachers can also derive significant information comparing two or more models of the same problem solutions provided by different groups. For instance, comparing the diagrammatic model of the solution of group AB (see figure 2a) with this corresponding of group KM, shown in figure 2b, one can distinguish differences in objects involved in each solution, in conflict points, identify items of intense collaboration in one group and low collaboration in the other group and so on.

TOOLS TO SUPPORT OCAF

An attempt has been made to support the OCAF Framework through a logging data storing and presentation tool. The tool has been implemented in the case of an environment of distance collaboration, where interaction was based on exchange of text messages and actions in the common activity space. The events are serialized and stored in a database. Actions are categorized according to the functional roles of Table 1. Classification of text messages is left to the researcher, since no structured dialogue tool has been used in this case. A web-based interface has been built, through which inspection of these log files and grouping of information is achieved. Views of interaction as presented by this tool are shown in figure 3.

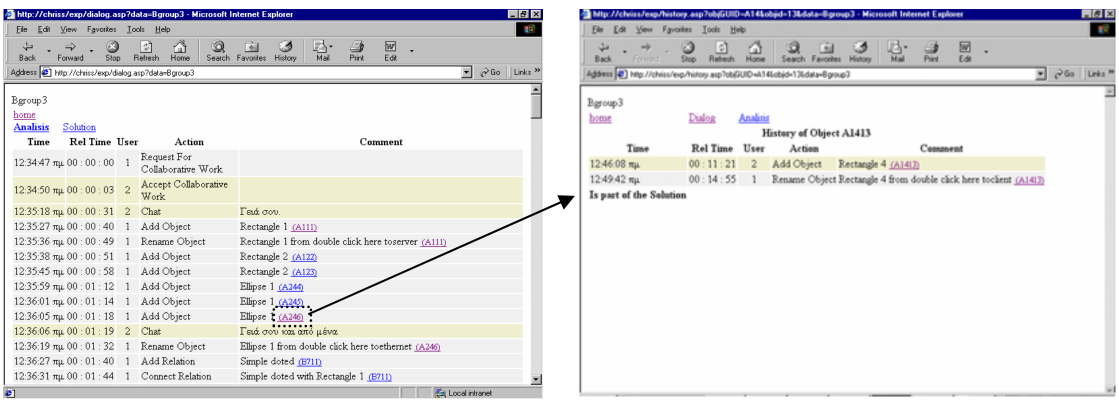

Figure 3. OCAF tool for log file visualization

In figure 3(a) interactions are presented according to the time dimension. Every time a new object is inserted in the activity space, a hyperlink is built to it, which allows the researcher to see the object view of this particular item, as shown in figure 3(b). Alternative views are also created according to actors, items of the solution, structure of the solution, etc. An interesting aspect is that these views are created automatically; since the information is built in a database and the web interfaces shown in figures 3 are created dynamically through queries to the database. The tool was proven useful to the analysis described in the previous section, while new functionality is planned to be built relating to the run-time use of the log files. Complementary tools are planned to be developed enabling an automated production of diagrammatic models of OCAF framework.

DISCUSSION

Collaboration is a phenomenon for which we lack adequate analytic models. It is not claimed that the complex phenomena of social interaction and particularly of collaborative learning can be comprehensively reconstructed by analytic models. These models are bound to be partial, capturing only specific facets of actions or interactions in groups. The value of an analytic model like OCAF, is related to its capacity to bring up interesting points of view and thus provide information to researchers relating to some of the following issues:

A) *The quality of the solution*: firstly it can identify solution items that take part of the solution. Further information that can help to interpret the solution and infer mental models of students are: (a) Items discussed and rejected and items that were abandoned due to a conflict. (b) The collaborative history of objects, for instance non appropriate solution items that have been derived from low collaboration, (c) The order of each item discussion (τ). Information on the problem solving strategy can be extracted by the study of some 'functional roles' of objects' solution history related to testing approaches and tools used (see analysis of Case study B)

B) *Collaboration modes and quality of collaboration*,: Information that can be derived can concern among others the following: (a) Degree of participation of group members, based on indicators such as distribution of solution items per member, (b) Contribution of group members to the developed solution, (c) Determination of roles of group members, and the degree of their involvement, (d) Existence of some functional roles (e.g. argumentation or test) (d) Density of interaction; (e) Identification of interaction patterns per item of solution.

Some of the above points are related to quantitative aspects of interaction, and appear often in studies of collaborative distance learning environments, while others relate to a more cognitive and meta-cognitive view, as for instance is the case of solution validation strategies. These questions have been effectively tackled using OCAF, as demonstrated in the presented case studies.

A second point relates to the diagrammatic form of the OCAF model. This contributes in a supplementary way to the analysis, providing a perceptual view. A teacher that examines and compares two diagrammatic OCAF models of solutions, can directly distinguish, for instance, solution objects that are not appropriate and were not discussed in a group, or others that were discussed a lot and revised. Such information can support teachers to propose intra-group collaboration in order to discuss specific issues.

The teachers can identify conflict points, not appropriate approaches and give advice on topics of the debriefing session internal to the group and recognize semantically significant differences between approaches on problem solving and advice further intra-group discussions.

Related to the diagrammatic form, one can consider this view as an attempt to relate the time dimension (predominant in interaction analysis) to the space dimension (predominant in diagrammatic solution representation). Various transformations of this view can make it suitable for different users. For instance, by adequate color-coding of the participants and their roles, the association of ownership to solution items could become vivid,. Even if the presented abstract form of this diagram may be useful to researcher or teachers, may not be appropriate to students. This representation can increase their cognitive load. In this case, alternative representations can be used, like the diagram of the produced solution itself, with associations to the history of interaction to each 'object' involved.

The framework was applied in two cases both of them involving diagrammatic problem solutions where the constitutive items of the solution were entities, relations and attributes or properties. It is believed that using the framework, similar models can be produced containing various kinds of solution items, the only restriction being that the problem solution is made of independent items. So many diagrammatic or object-based solutions, like diagrams, puzzles, etc., can be analyzed In contrary, this framework cannot easily be applied in text-based or algebraic solutions.

In conclusion the presented work is part of a research agenda that seeks to conceive and develop flexible and open tools, able to assist users of collaborative learning environments to monitor and/or self-regulate their actions. The tools are designed to be open in order to allow a substantial adaptation of participants' *functional roles*, and are designed to be linked with different kinds of systems, based on various dialogue interfaces among collaborators.

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