Designing Collaborative Learning Systems: Current Trends & Future Research Agenda

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Abstract. The research community, in order to support learning as well as collaboration, has designed systems, which, distinctive from common web-based ones (simply enabling collaborative activities), constitute new cognitive and meta-cognitive tools. The paper proceeds with a categorization of the main tools and functions that characterise collaborative learning systems (designed for primary/ secondary/ higher/ education) in order to discuss the current trade-offs. It proposes a design framework for collaborative learning systems that are addressed to primary & secondary education. This framework is derived from considerations of cognitive psychology, science education, and CSCL community research results. The paper concludes by presenting the main themes of the actual research agenda, which is intended to help design systems that can be integrated into primary and secondary education contexts.

Keywords: Collaborative learning systems, primary / secondary education, trade-offs, framework

INTRODUCTION

The Computer Supported Collaborative Learning (CSCL) community works on theoretical frameworks, tool and artifact design, appropriate architecture and development approaches as well as various methods for a significant qualitative and quantitative evaluation of collaborative situations. The community also deals with the implementation of actual educational systems, collaborative learning activities and new pedagogical approaches, while seeking new roles for various implicated agents (i.e. students, teachers). Ultimately, it aims at: (a) producing tools and systems, (b) developing our understanding of learning processes and (c) finding the best ways to implement new approaches and tools into actual educational systems. The reader may find significant review papers exploring the evolution of research on collaborative learning (Dillenbourg et al 1996), the meaning of collaborative learning (Dillenbourg 1999), the epistemological foundations of CSCL (Lipponen 2002; Paavola et al, 2002) and learning effects and best practices (Lehtinen et al, 1998). All of these topics have been the subject of theoretical reviews and foundation papers.

However, many questions remain unanswered. "What are the *main design achievements* of this research field?" "What are the *current trade-offs* and what are the various designers' choices concerning significant design aspects?" "What are the main *actual design questions* that preoccupy researchers and form the *research agenda* for upcoming years?" The exploration of these general questions serves as the objective for the present paper.

There are many ways to promote collaborative learning: gathered around the computer, through new technological gadgets, through a balanced combination of the various tools existing on the web, etc. In this paper, we have based our analysis and discussion of collaborative systems on those that have been explicitly designed for learning purposes and concern a wide range of learning activities for primary, secondary or higher education. The paper proceeds to present a categorisation of the main tools and functions that characterise collaborative learning systems so as to discuss the current trade-offs. In order to synthesize the new design trends of collaborative learning systems that are addressed to primary or secondary education, a framework of analysis is proposed. This framework is derived from considerations of cognitive psychology, science education, and the CSCL community research results, while also taking into account the social context of the school. Finally, the main axes of the actual and future research agenda are pointed out.

TRADE-OFFS ON COLLABORATIVE LEARNING SYSTEMS DESIGN

Before discussing the means for supporting collaboration, it would be useful to categorize collaborative learning systems according to the kind of collaborative activities that they each support, given that the main means of dialogue and actions that students dispose depend on the learning activity itself. In general, existing systems can be divided into two main categories:

(a) *Action-oriented collaborative systems*: Some collaborative systems are based on the idea of starting from a student's actions, expressing and capturing the student's emerging knowledge and then making this knowledge-representation itself a subject of artifact-centered discourse. This is the case, for instance, of action-oriented systems based on disciplinary representations, including those of C-CHENE (Baker & Lund, 1997), COLER (Constantino-Conzalez & Suthers, 2001), COMET (Soller 2002), Cool-Modes (Hoppe & Gabner, 2002), Algebra-JAM (Wu et al. 2002), CoLab, (van Joolinger, et al., in press), MODELLINGSPACE (Dimitracopoulou & Komis 2004), as well as Convince Me (Ranney et al, 1995) and SenseMaker (Bell, 1997). In most of these systems, the underlying learning activities are mainly based on synchronous communication.

(b) *Text-production oriented systems*: This category of collaborative systems invites students mainly to produce a written text or report in a collaborative or cooperative way. For instance, in Knowledge Forum (Scardamalia & Bereiter, 1994; Hakkarainen & Lipponen, 1998), CoVis (Pea et al, 1994) or Fle3 (Leinonen & Kligyte, 2002), students have to create text-based files presenting their point of view on a topic or report on a whole activity. This constitutes the principal activity addressed to wide groups that are focusing on building their shared knowledge and developing into a community of learners. Also belonging in this category are those systems supporting collaborative argumentative writing, such as COSAR (Erkens et al, 2002). In most of the systems of this category, the underlying learning activities are mainly based on asynchronous communication.

An analysis of the existing collaborative systems shows that a number of tools and functions are designed and implemented in order to facilitate or better support the collaborative learning process. In order to discuss these in a brief way, we have viewed them through the lenses of their support for the specific *high-level functions* that should be performed during collaboration:

- *(A) The appropriate means for dialogue and action:* They provide the essential means for the collaborative learning activity itself.
- *(B) The functions for workspace awareness*: They are related to up-to-the-minute knowledge about partners' actions in a closed collaborative scheme or in a wide community of collaborators.
- *(C) The functions for supporting students' self-regulation or guidance*: They support or directly guide students' reasoning on a metacognitive level.
- *(D) The facilities related to teachers' assistance:* They are essential, especially when the systems are addressed to students of primary and secondary education.
- *(E) The functions related to community level management:* They provide significant tools and functions for management of the activities and material produced amongst a wide community.

One central aspect of work in CSCL involves concerns over design trade-offs. Anything designed is, usually, only one choice among many possibilities that were considered as well as even more possibilities that were never considered. Therefore, why is a focus on trade-offs important? Because much of the critical discussion centering around collaborative learning takes an extreme position on one or two dimensions of the design trade-off, overemphasizes those dimensions at the cost of acknowledging the most basic point that trade-offs are inevitable in design.

Let's consider some important trade-offs in thinking about the design of collaborative environments. Currently, the main trade-offs (that is to be) considered by designers are related to the principal functions of CSCL systems mentioned above:

(1) The means of dialogue (an always-crucial aspect in collaborative learning) deals with at least the following three specific trade-offs: (i) between free and structured dialogue, (ii) between parallel and embedded communication tools (iii) and that between text-based and oral dialogue tools;
(2) The trade-off related to the coordination of action versus dialogue (influencing the students' freedom);
(3) The trade-off between metacognition support for self-regulation and teacher support;
(4) The more general trade-off related to designing an action-based system or a system based on text production (that could influence the new tendencies of a system's main features).

Trade-offs Related to the Means of Dialogue

Systems, either action-based or text-based, and even if they dispose a shared workspace to the collaborators, all provide one or more dialogue tools. These means are considered crucial not only for collaboration but also for learning. Externalization achieved through written dialogue that is conducted during collaborative activities may have significant effects, especially for conceptually rich learning activities (e.g. those related to science or mathematics). Interactive linguistic exchanges among people play an essential role in the elaboration and perpetuation of scientific concepts, while the primary use and mechanism for acquisition of these concepts is the result of social interaction.

In designing the means of dialogue in a learning environment that supports synchronous collaboration, one has to deal with at least the following three specific trade-offs between: (i) free and structured dialogue, (ii) parallel and embedded communication tools, (iii) text-based and oral dialogue tools.

The Trade-off Between Free and Structured Dialogue

The related discussion mainly concerns the eventual choice between conducting a free chat or a structured one in synchronous collaboration mode and it is also related to the possibility of design-threatened forums or chats.

Let's consider the case of synchronous collaboration. A principal-related designer's question is highlighted by the choice between a free chat interface and a structured dialogue interface. Such a question must be examined by looking at what conditions and for what task users may need each function. Research results show (Baker & Lund, 1997) that pairs who use the 'free' communication mode more than the 'structured' one produce more 'off-task' statements than those who prefer the 'structured' mode. However, we could hypothesize that the appropriateness of a free versus structured interface is not independent from the type of content being uttered. For example, the free chat interface that allows unstructured, synchronous dialogue, seems to be more appropriate during the initial brainstorming phase of problem-solving, the discussion on problem-solving or modeling strategy, eventual decisions regarding task distribution among different members, etc. It seems that management of the problem-solving process or of a project elaboration is more often expressed by using the free section, while the structured one more often expresses task and strategy contributions. In all cases, the interest of the designers of dialogue tools aimed at promoting collaborative learning is deepening the space of debate and producing *epistemic interactions* (Baker et al, 2001). This ultimately feeds argumentation, particularly that which occurs at a conceptual level and can stimulate reflection on subjective explanatory systems (Baker et al. 2003).

Related to the appropriateness of structured chats, there are objections that we must have in mind when designing CSCL environments: (a) Practitioners believe that if the participants of a collaborative learning situation could choose between a structured communication mode and a 'free' communication mode, they would definitely choose the latter. But, some experiments (Jermann, 1999; Baker & Lund, 1997) have shown that the structured section of the interface was more frequently used than the free section. (b) Requiring learners to select a sentence opener before typing the remainder of their contribution may tempt them to change the meaning of the contribution to "fit" one of the sentence openers, thus changing the nature of the collaborative interaction. For this reason, it is critical that the sentence openers enable the widest possible range of communications with respect to the learning task (Soller, 2002). (c) Finally, it is to be noted that, besides the gains that learners may have achieved through a structured dialogue, this dialogue is also crucial for realizing the benefits of a significant meta-analysis of collaborative activity, constituting another advantage of a structured interface. However, the sentence openers are not always used as intended, resulting in subsequent contributions that would not necessarily correspond to the discussion skill represented by the sentence opener (Dillenbourg, 2002). This is something that we must have in mind if the corresponding data is processed for analytic purposes.

In the case of asynchronous or even synchronous dialogue, another kind of structured dialogue tool to be considered is a *threaded discussion*, or *tree structure*, that may be viewed in a summary form. This kind of structure is created just after each dialogue statement (e-mail, chat, forum) is entered, thus there's no need to intervene in the students reasoning during conversation.

Up to the present, a number of dialogue tools have been developed, forming a broad spectrum of possibilities, from the unstructured to the structured and onto the abstract (e-mail, chat, threaded forum, structured chat, post-it annotations, concept maps, specific representation formalisms, etc.). Recent research has explored the differences between students working only with an on-line chat and those working with a chat and a graph dialogue tool (Baker et al., 2003). The results showed that students who had both a chat and a graph dialogue tool at their disposal produced more arguments than their counterparts.

The trade-off, in terms of design, can be resolved by the simultaneous support of a wide range of dialogue tools offered to users. We consider that it is important to provide students with multiple tools of dialogue, to assure flexibility of use for different instances and according to the apparent needs of different phases of collaboration as well as according to the needs derived from the specificity or the complexity of the task.

The Trade-off Between Parallel and Embedded Representations and Tools for Dialogue

A recent trade-off has appeared between the "parallel tools" and the "embedded tools" for dialogue, especially apparent when users work in action-driven systems. Most of the existing systems offer shared artifacts and discussion tools on entirely separate windows. This seems to lead to a disjointed discourse about the artifacts, even if one can work around this problem by placing the discussion tools next to the artifacts under discussion (Reeves & Shipman, 1992). D. Suthers refers to these as *parallel communication tools:* defined as tools that do not assure any coordination between the discourse and disciplinary representations (Suthers, 1999). In cases of separate artifacts, there is a greater distance between the object of the discussion and the corresponding dialogue, hence the cognitive load in processing them. Thus, the questions to reflect on concern whether it's possible and, if so, how to support 'embedded discourse representation,' a process that embeds comments directly into the display of the artifact under discussion. In informal and formal studies, students appear to prefer embedding their discussion directly into the artifact window (as comments) rather than switching between that window and the chat window (Wojahn 1998; Suthers, 1999). Because the discourse always takes place in the context of the artifact, *embedded communication tools* have the advantage of making it easier to refer to parts of the artifact and to recover the portion of the discussion that is concerned with a given part.

Some embedded communication tools, designed to establish and carry on a discussion in the context of the visual artifact include: (a) *Annotation tools* (sticky notes) that allow the embedding of comments directly into the display window of the artifact under discussion (Dimitracopoulou & Komis, 2004); (b) *Drawing*, the disclosing or indication of a representation or a part of a representation (e.g. diagram) under discussion; and (c) *Highlighting* parts of a diagram under discussion. In reality, this final option supports 'gestural deixis' (Suthers et al., 2003), enhancing the deistic value of the cursor by making its location more visible. If the user passes the cursor over an object, the object will be highlighted in a particular color and if the user deliberately selects an object with the cursor, this object is then highlighted in another color. In fact, all three of these design options are metaphors for the actions undertaken by pupils when working in the traditional paper-pencil mode.

Some disadvantages are that the record of discourse is fragmented across the artifact, making it more difficult to get a sense of the whole discussion or to notice relevant relationships between discussions about different parts of the artifact, and the possibility that the artifact becomes cluttered with comments. It would be beneficial, therefore, to be able to recover chronological versions of the discourse and perhaps to index the discourse in ways other than those done so by artifact components or chronology.

The trade-off between parallel and embedded communication tools could be resolved by conceiving of a system of *linked dialogue representations* tools, which would provide a logical link between tools that could then be viewed in virtually embedded ways if needed. It would also be useful to be able to switch between parallel and embedded representations (create a note in one representation and view it in another) (Suthers et al, 2003). This approach could resolve the conflict between the typically linear structures of parallel discourse tools and the contextual indexing of embedded discourse representations.

The Trade-off Related to the Coordination of Action and Dialogue

Related to the question of the coordination of action during synchronous collaboration, we consider that two interrelated trade-offs have emerged: (a) the existence or not of specific coordination protocols, (b) the specification or not of the 'rights' on collaborator contributions.

(a) Restricted collaboration protocols vs free ones: During collaborative learning, a common final product is expected from the participants, making a shared workspace and a shared point of reference necessary. In the case of synchronous collaboration, the question that arises is whether or not the production of the final product must be coordinated or better left free. This question is applied for action-driven systems as well as text-driven ones.

An implication of a restricted protocol (applied using, for instance, the metaphors of a 'key or pencil exchange,' or even 'traffic light') is that deadlocks can be created in cases where one partner cannot proceed with problem-solving alone and at the same time refuses to pass the key over to the other partner. The advantage, however, seems to be that the protocol maintains clear semantics of a participant's actions and roles in the shared workspace (Soller et al. 2002; Feidas et al, 2001).

Currently, there is also an interest in examining the possible need for communication protocols in the case of oral dialogue. Is the application of an oral dialogue coordination system needed or should there be a free one, where participants are invited to regulate their oral discussion by social agreement? In the 'Lyceum Project' (Bunkingham et al. 2001), using a videoconference system without imposing a control (i.e. anyone can speak anytime), adult participants 'learn' to take turns and maximise flexibility for different kinds of 'meetings.' In such a case, interactional fluidity is a useful and important skill for newcomers to learn. Another approach could require the use of metaphors such as conjuring up 'microphones' that would either be 'passed' among group members themselves or by a 'chairperson/group leader.'

It is to be noted that coordination protocols were eventually applied in all the early systems, making them easier to implement. However, where both approaches are technically possible, there's a need to re-examine the necessity of a coordination protocol (Dillenbourg, personal communication, May 2002), and specifically, to take into account the preferences of users themselves.

(b) Rights on partner contribution modification and the identification of ownership: In fact, the question of coordination protocols is also related to the concept of "*workspace awareness*" and the '*ownership*' of parts of the collaborative construct. What are the rights that each partner has on the contributions of the other partner? Some designers have left this free (e.g. in 'Modeler Tool,' Koch et al., 2001), without utilizing any locked mechanism, while others prefer to lock them to all other persons than the object's owner (e.g. 'Representation,' Komis, et al., 2002). In order to answer this question, an experiment was organised using two alternative collaboration protocols (Feidas, et al. 2002). Groups "A" had no ownership control, while groups "B" maintained ownership of introduced objects, so partners were not allowed to modify objects introduced by their peers. In the case of groups "B", every time a partner needed to modify an object of different ownership, a negotiation phase had to be initiated in order to convince the object's owner on the need for the proposed modification. By contrast, the groups without ownership control, displayed instances of disagreement during collaboration. We could argue, therefore, that eventually students need *a clear indication of 'ownership'* (with direct or indirect indication of the names of the owners of each item) in order to regulate their activity and avoid this kind of conflict. Instead of locking mechanisms, however, we propose the addition of optimistic, concurrent control by supporting awareness, a process indicating exactly who currently uses which component. This could give the student more freedom and foster teamwork.

The Trade-off Between Metacognition Support for Self-Regulation and Teacher Support

This is a trade-off that actually arises simultaneously with an increasing research interest in the production of tools and functions for student and/or teacher support (Muhlenbrock & Hoppe, 1999; Jermann et al, 2001, 2002; Barros et al, 2002, Avouris et al, 2003; Martinez et al, 2003; Morch et al, 2003; Fessakis et al, 2004).

Let us first examine the actual possibilities, tendencies and new requirements for the self-regulation of student support. The skill of self-regulation is referred to as one of the meta-cognitive skills that allows a learner to concentrate on his/her own thinking process, successfully controlling it in order to independently achieve his/her goals (Brown, 1987). Systems that contribute in this direction are not those that reflect interactions ("mirroring systems," according to Jermann et al., 2001), but those that monitor the state of interaction by providing collaborators with literal information (Barros et al., 2002) or visualizations that can subsequently be used to self-diagnose and self-regulate interaction. Visualizations typically include a set of indicators that represent the state of interaction, possibly placed alongside a set of desired values and metrics for those indicators. Different kinds of appropriate visualizations have been produced, including graph-like visualizations, such as bar charts, pie charts, etc. that are used in problem-solving activities (Jermann et al, 2002, Fessakis et al, 2004), 'nested boxes' used in forum discussions, (Simoff, 1999) and even social networks used in cases of wide community exchanges (Martinez et al, 2003). The hypothesis is that the visualization structures of student discussion and actions, conducted through a suitable representation, can assist students in developing meta-cognitive mental activity and subsequently self-regulate their collaborative activity.

In general, examining current interaction analysis as related to literal or numerical information, or better, implemented visualization tools that are intended to function as meta-cognitive tools, we can distinguish that: (a) information may concern the whole group or each member of the group, (b) analysis may be based only on the actions of collaborators or their dialogues, (c) analysis may concern only the collaboration quality or the content of the activity, and (d) analysis may be based on either basic indicators (e.g. participation rates) or higher order indicators (e.g. related to collaboration modes or the quality of the solution).

It is to be considered that, for instance, in collaborative problem-solving, meta-cognition is not only related to the interaction itself but also to the strategic reasoning linked to the task. There is the assumption that regulation of the interaction and regulation of the task are closely related mechanisms and their co-occurrence facilitates coordination. Instead, however, the existing meta-cognitive tools for collaborative activities are based on statistical indicators of participation and collaborator actions or messages rather than on higher order qualitative indicators. These aspects are further discussed in Avouris et al. (2003) and Jermann et al. (2001).

The whole question of the design of appropriate meta-cognitive tools must be further investigated by the research community and in relation to: the category of students' activity (e.g. a game or a high cognitive demanding task), the collaboration mode, the age of pupils, and the kind of group (e.g. small, large group).

Up to the present, researchers have focused more on student self-regulation, while they have neglected teachers. Yet, students naturally seek the teacher's help when they realize that more information is needed to profitably continue an interaction. Therefore, we consider that most of the existing collaboration systems present limitations when used by young students in real school settings. Some of these 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. Two crucial questions are, *"How could we help teachers fulfill* *those responsibilities in computer-based collaborative situations?*" and "*How can teachers be supported with appropriate tools to help students*?"

There has not been enough research done on the significance of the teacher's role during network-based collaborative learning and the fact that teachers can derive useful knowledge from observing or participating with their students in CSCL environments (Lund & Baker, 1999). While some research has focused on the kinds of teacher interventions, there haven't been any looking at how we could support teachers to proceed to these interventions and what their needs are during the coaching of collaborative students.

In order to examine the needs of teachers during synchronous collaboration and determine corresponding requirements, experimentation was conducted (Petrou & Dimitracopoulou, 2003). The question was to examine teacher behavior during synchronous problem-solving with known and currently accepted learning activities (not innovative ones). Teachers applied two complementary scenarios for their interventions: (a) on-line supervision of a group collaborating in a synchronous mode, and (b) off-line analysis of the preceding intervention. Here, each teacher studied the students' interactions, then during the next session intervened in order to discuss some concepts or to propose new problems. The analysis of individual and panel interviews with teachers concluded that there is a need to design and develop better tools or partial functions, including (a) supervising tools and facilities, (b) elaborated and linked history of the whole interaction and (c) tools that produce an automated assessment of students' interactions. It appears that the most difficult requirement to accomplish would be the third one: *How to provide a rich variety of analysis output to assist teachers or facilitators?*

Actually, the underlying design and research work is in progress and is merely at a premature stage. We consider that the existing approaches (regarding the support of students' self-regulation and guidance from the system or support for the teacher in order to assist his/her students) are all valuable. However, it would be much more so if these approaches could be combined in a single learning environment allowing control or the self-regulation to be divided among the involved agents (collaborators, teacher, system).

The Trade-off related to the different kinds of collaborative learning environments

Up to the present, most designers and researchers have focused their work on one of the two dominant kinds of collaborative learning systems: (i) systems that promote collaborative problem-solving and work with a small number of collaborators, such as action or argument-oriented systems (e.g. COLER, C-CHENE), and (ii) systems that are directly addressed to a wide community, usually aiming at collective knowledge-building and understanding through text production (eg. CoVis, Knowledge Forum). The design of the first category of systems puts more stress on the tools for shared action, dialogue and meta-analysis, while the design of the second category focuses on the shared document repository, the structure and the multiple visualization of the material created from the community, the discussion forums, etc. The first category uses more synchronous communication tools, while the second one is mostly based on asynchronous tools.

Nowadays, the trade-off between these two general categories does not seem to be so relevant. On the one hand, researchers on the community-based systems, have recently recognized that it is worthwhile to incorporate some tools and functionalities for synchronous communication and collaboration (Lethinen, 2002), allowing students to organize their work, clarify ideas and enhance social awareness. On the other hand, systems for collaborative problem-solving, when used in a school environment, can enrich learning objectives when they support exchanges between students in a class. This includes the exchange of materials, ideas and difficulties, fostering an inquiry learning process. In this sense, we consider that every collaborative problem-solving system needs to be accompanied by a community support system and, therefore, incorporate tools and features used by the latter. Thus, repositories, group formation and off-line/social awareness functions are important features in any environment. Currently, this approach started to be adopted by some collaborative problem solving systems, such as Cool Modes and MODELLINGSPACE.

TRENDS IN NECESSARY TOOLS AND FUNCTIONS

Synthesizing the aspects presented in the previous analysis on the design trade-offs related to tools and functions, and remaining faithful to our central aim of designing advanced systems that support collaborative learning in real school contexts in an essential way, we propose a design framework consisting of the following four fundamental considerations:

(A) *A vision of all agents and cognitive systems involved in collaborative learning settings:* The agents that seem to be considered in some collaborative environments are often seen from a one-dimensional point of view. In reality, during collaboration the main actor is neither only the *individual-member* of a collaborative team nor only the *team as a whole*. Both of these 'aspects' are important, but equally so is the case of *the whole community* formed of individuals and groups collaborating in various modes. On the other hand, a learning process (at least in the frame of primary/secondary education), involves both learners and *teachers*. The learnercentered design approach, being dominant during the last decade, has positively influenced designers, but has also presented the following drawback: by focusing in principle on the individual learner, it takes the other agents involved out of the cycle (Dimitracopoulou, 2001). These agents may form *one or more cognitive systems*, in the sense of distributed cognition theory (Salomon, 1995). Consequently, all agents involved in the process must be considered important and may need to have specific tools at their disposal. Thus, we need to consider each actor: (a) the individual, (b) each specific team, (c) the whole learners' community that is formed and (d) the teacher(s).

(B) *A complete view of the necessary tools and functions supporting collaborative learning:* In the ideal case, each agent and each cognitive system needs some basic tools to fulfill five general functions that allow and support collaboration for achieving learning progress. These five functions are: (a) *Action and discussion function*s, leading to action or text production tools, as well as dialogue tools; (b) *Course Management,* leading to tools for the management of the learning material (e.g. repositories, group formation tools, etc.); (c) *Workspace awareness' functions,* leading to functions related to immediate workspace awareness as well as to a larger social awareness of all the events that happen in the wider learning community; (d) *Analysis and meta-analysis tools* supporting self-regulation and metacognition for students, including teachers' tools for supervising and analyzing collaborative interactions either in an on-line or off-line mode; (e) *Help and Advising functions* leading to simple help systems or more advanced advising systems for students and teachers.

(C) *A vision of a mixed category of collaborative learning systems:* Analyzing what kinds of tools are developed per category of systems, it is determined that there are two dominant systems' categories: (a) systems that focus on the collaboration between a small group of learners and (b) systems that are addressed from the beginning to a wide community of learners. These two categories are actually sufficiently developed, given the specific focus of each kind of environment (problem-solving or exchanging ideas). Therefore, it is currently possible to develop systems that draw from both of these categories, presenting mixed features.

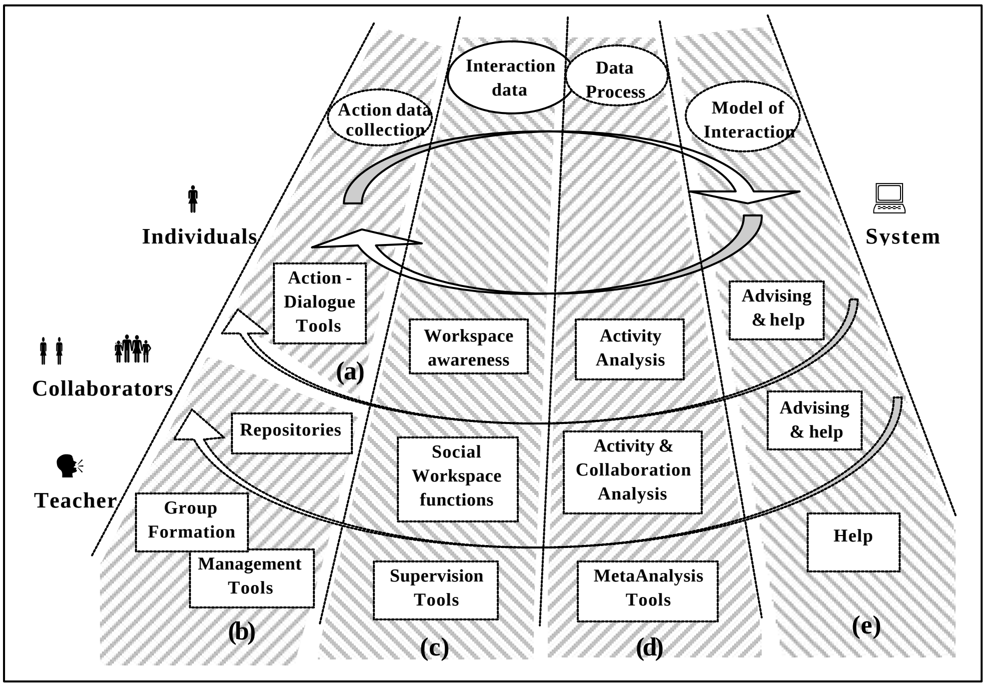

Figure 1. System processes during collaborative activity that offer tools and functions to the involved human agents

(D) *A vision of the control of the collaborative process as distributed to all the agents*: In our point of view, it would be fruitful to work on the direction of *expanding the management of the collaboration* to all the agents: 'individual,' 'collaborators,' 'teacher' and 'system.' This expanded collaboration management would be possible, according to an approach based on a number of general *principles,* allowing for determining the need for an agent (human or artificial) to intervene as well as dictating the specific sub-role that this agent should undertake. The current approach is often based on a well-defined desired state, according to which the system advises the collaborators. This approach does not seem to be the most appropriate, given that it is valid only in very specific cases of activities, problems, conditions and student profiles. Generally, knowledge construction activities are open and flexible, while such a model is quite restrictive.

According to these fundamental considerations, we could examine now, how a generic collaborative learning system functions, how it processes the whole interaction, what functions it assures and to whom it is addressed (see Figure 1). The individual user has available the tools for action and dialogue in order to function in a private workspace or interact and collaborate through a shared workspace. In order to manage production, users have also access to specific tools (e.g. repositories). The collaborative learning system internally collects the data of each user's actions as well as that of the interactions among all participants and then processes this data, eventually constructing a model of actions and interactions. This system assures the continuation of the five main functions that are necessary to support collaboration. However, according to the first consideration, we can argue that there exist at least three simultaneous processes that correspond to the three main agent profiles: individual, collaborators and teacher. Thus, in order to fulfil individual needs the system may advise, offer information (visually or verbally) based on activity analysis or support other basic functions such as the assurance of workspace awareness. In order to support the group of collaborators, it may produce advice, present information derived from high-level indicators through a meta-analysis of collaborative activity or raise social awareness. Similarly, help functions addressed to teachers may be assured and supervision tools as well as individual, collaborative or even comparative information may be presented, based on an analysis of all interactions.

CONCLUSIONS: RESEARCH AGENDA TOWARDS MORE APPROPRIATE SYSTEMS FOR REAL SCHOOL SETTINGS

There are many ways to promote collaborative learning: gathered around the computer, through new technological gadgets, through a balanced combination of various existing tools on the web, etc. In this paper, we have based our analysis and discussion on collaborative systems that have been designed for learning purposes and a wide range of learning activities. In all these systems, collaborative learning is viewed as a pedagogical method that can stimulate students to discuss information and problems from different perspectives, to elaborate and refine these in order to re-construct and co-construct (new) knowledge or to solve problems. In such situations, externalization, articulation, argumentation and negotiation of multiple perspectives are considered the main mechanisms that can promote collaborative learning (Dillenbourg et al., 1999; Baker et al., 2001; Veerman, 2000). These systems have allowed for new learning settings and have managed to develop new cognitive and metacognitive tools to support learning and collaboration.

The evolution of research on the design and development of collaborative learning systems have had an effect on the emergence of some significant trade-offs related to the means of dialogue, the coordination of action and dialogue, the self-regulation/metacognition support of students and the analysis and meta-analysis tools for teachers as well as recognition of the differences between 'problem-solving oriented systems' and 'wide community systems'.

In conclusion, we argue that the research design agenda of the immediate future needs to be focused on the following axes:

i) Accentuation of the effort to produce rich systems: The unification of designers' efforts working on different collaborative system categories and under an open vision of all the possible 'human cognitive systems' formed during various collaborative modes, could produce richer systems, which are more appropriate for various collaborative settings, conditions and contexts.

ii) Elaboration of powerful analysis methods of collaborative interactions: Researchers are in the process of developing methods that have the potential to derive rich analysis and meta-analysis results, taking into account a number of aspects: (a) the whole content of the activity with both actions and dialogues, (b) the collaboration modes and quality, (c) the context of the collaboration and (d) each cognitive system's (individual, group, wide community) needs.

ii.a) Development of visualized meta-cognitive tools addressed to students: For this purpose, research has to focus on the investigation of appropriate visualization modes that could produce metacognitive tools that are able to support young students in both learning and the collaboration process.

ii.b) *Development of visualized tools addressed to teachers:* It has just recently been acknowledged that one actual new research direction should be related to how we could take profit from the traces/transcriptions of students in order to facilitate the teacher's analysis task allowing him/her to apply diagnosis and, thereafter, scaffolding. This is needed to provide appropriate analysis and meta-analysis results with appropriate visualizations that could support teachers when needed to intervene during or after the interaction.

iii) *Production of flexible and negotiable environments that respect the sustainability and reusability of the elaborated work:* Lessons learned from technology-based learning environments in schools suggest that we need to consider the school as a community of practice, creating systems that allow people to perform as well as they are able to and then to amplify, transform, and extend their work to new or additional outcomes. Brown (2000) argues that information-driven technologies and their implementation need to be grounded in the social life of the school. Given that most of the schools do not have a long history in the exploitation of these environments, it is important to provide *flexible architectures and customisable tools,* studying how they work in schools, particularly in different cultural and educational contexts. Research often concludes after a short period of implementation time, without working with the possibility that students and teachers can adapt and negotiate the use of tools for their perceived needs (Baker et al. 2001; Dimitracopoulou, 2001). Additionally, it is crucial to assure the *sustainability and reusability* of the work done in a software development perspective, designing interoperable systems that are open and easily extendible (Hoppe & Gabner, 2002).

iv) *Collaborative learning activities and tasks regarding various collaboration modes:* We need to always keep in mind that it is not only the features of the technology used but especially the way technological artifacts support collaboration in real settings (Lehtinen, et al 1999). A crucial parallel research agenda concerns the design of appropriate collaborative learning activities and modes for different learning purposes and student age levels (Dimitracopoulou & Ioannidou, 2003). The effort to elaborate on the semantics of collaborative scripts is promising and assists in raising the awareness of a rich range of choices (Dillenbourg, 2002).

(v) Exploration of the new possibilities offered by ubiquitous computing and wireless devices: As technology evolves, new design and research possibilities are revealed. Specifically, the ubiquity of computing and handheld computers offers new physical media, different from those of traditional computer-supported collaborative learning applications (Roschelle & Pea, 2002). Subsequently, what is needed is an investigation of many of the new functions and interfaces of these promising devices, assuring their corresponding usability. As well, research must look at how such devices open up a world of new powerful learning activities.

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