Computer Supported Collaborative Learning: A Review

Erno Lehtinen[1)]

Kai Hakkarainen[2)], Lasse Lipponen[2),]

Marjaana Rahikainen[1)] & Hanni Muukkonen[2)]

[1)] University of Turku

[2)] University of Helsinki

CL-Net Project

SUMMARY

One of the basic requirements for education in the future is to prepare learners for participation in a networked, information society in which knowledge will be the most critical resource for social and economic development. Computer-supported collaborative learning (CSCL) is one of the most promising innovations to improve teaching and learning with the help of modern information and communication technology. Collaborative or group learning

refers to instructional methods whereby students are encouraged or required to work together on learning tasks. It is widely agreed to distinguish collaborative learning from the traditional 'direct transfer' model in which the instructor is assumed to be the distributor of knowledge and skills.

Recent research on the role of collaboration in learning has tried to find deeper theoretical frameworks that could better guide the developing of technology-aided learning environments. A distinction between cooperation and collaboration is conceptually central in this review. The distinction is based on different ideas of the role and participation of individual members in the activity. Cooperative work is accomplished by the division of labour among participants. It is an activity where each person is responsible for a portion of the problem solving, whereas collaboration involves the mutual engagement of participants in a coordinated effort to solve the problem together.

A technologically sophisticated collaborative learning environment, designed following cognitive principles, could provide advanced support for a distributed process of inquiry, facilitate advancement of a learning community's knowledge as well as transformation of the participants' epistemic states through a socially distributed process of inquiry. All components of knowledge-seeking inquiry, such as setting up goals, research questions, explanations or search for scientific information, can be shared or distributed among inquirers. A socially distributed process of inquiry provides strong support for the development of the participants' metacognitive skills. Further, computer-supported collaborative learning appears to engage students to participate in in-depth inquiry over substantial periods of time and to provide socially distributed cognitive resources for comprehension monitoring and other metacognitive activities. Hence it is plausible to assume that imitation of good cognitive practices and appropriation of more advanced processes of inquiry can be elicited by creating learning environments that mediate all stages of the process of inquiry, not just the end result. This, in turn, would allow students to become aware of their conceptual advancement, as well as of changes in their practices of inquiry.

Many researchers have shown how very different technical applications can be used to facilitate collaborative and distributed teaching and learning including special network applications for CSCL, different multimedia/hypermedia applications and experiential simulations. It is not only the features of the applied technology but especially the foem of implementation of the technology which support student collaboration. Local area networks, wide area networks and the global version of the latter (Internet) provide education with a variety of mediating tools for collaboration (e-mail, electronic bulletin boards, conferencing systems, and specialized groupware). In the research literature there are descriptions of several systems especially developed for various educational purposes.

Large meta-analyses on the effectiveness of computers have shown that, in the majority of experiments the use of technology has markedly improved the learning outcomes. These studies do not, however, distinguish between different pedagogical ideas on how computers have been implemented in classrooms. Thus it is impossible to make any conclusions about the effectiveness of CSCL on the basis of these general impact studies. Several empirical experiments offer evidence that the well-known CSCL environments like CSILE and Belvedere have proved to be helpful for higher order social interaction and, subsequently, for better learning in terms of deep understanding. What is still lacking is the evidence that the same results could be achieved widely in normal classrooms. It is also possible that similar positive results could be achieved in classrooms carrying out the same collaborative activities without computers.

Although hundreds of papers on CSCL have been published during the last few years, our review shows that there are not too many well controlled experiments, which could answer the questions concerning the wider applicability of CSCL in normal classrooms and the added value of computers and networks in comparison to collaborative learning environments without technology. Most of the publications studied for this review described the systems and conditions as well as the students' conversation processes but presented no data on the learning outcomes. One could argue that this is because of the different paradigms or metaphors of learning adopted in these studies.

Several different models and technical tools have been developed for CSCL. There are some well known systems which have had an exceptional meaning in the development of the theory and practice of CSCL. A review of the best practices is presented including more detailed descriptions of the CSILE, the Belvedere system and the CoVis project, developed in Canada and the United States.

?? Several important aspects of knowledge-seeking inquiry characteristic of scientific research outlined above are implemented in the structure of the Computer-supported Intentional Learning Environment (CSILE). There is evidence that CSILE, in fact, facilitates higher-order cognitive processes and collaborative knowledge-building. Evaluations comparing CSILE and nonCSILE classrooms at the elementary level have shown significant advantages for CSILE.

- ?? The Belvedere system is based on long-term research on computer-supported learning environments. Belvedere focuses and prompts students' cognitive activity by giving them a graphical language to express the steps of hypothesizing, data-gathering, and weighing of information.

- ?? The Learning Through Collaborative Visualization Project (CoVis) is engaged in the research and development of new approaches to high school science education through collaborative project work with advanced networking technologies, collaborative software, and visualization tools.

Presently, although the scientific community has considered the principles of CSCL highly promising for the development of future learning environments, this is not yet the case among practicing teachers. For example in recent large survey studies, Finnish teachers did not regard collaborative learning as an important application of computers. This result is certainly partly due to the novelty of the CSCL ideas in schools but it also indicates that the theoretical and practical principles of CSCL are still too immature to be widely applied in practical educational reforms. There is a need for theoretically well grounded development of CSCL practices and tools which are adequately embedded in the European educational context. The results of previous research also highlight the importance of carefully analysing the presuppositions of the application of technology-based instructional innovations in practical classroom situations.

INTRODUCTION

One of the basic requirements for education in the future is to prepare learners for participation in a networked, information society in which knowledge will be the most critical resource for social and economic development. Educational institutions are being forced to find better pedagogical methods to cope with these new challenges. In this development it is expected that computers could play an important role in restructuring teaching and learning processes to be better prepared for future challenges. Computer-supported collaborative learning is one of the most promising ideas to improve teaching and learning with the help of modern information and communication technology. Still in the late eighties most experiments on computer-supported learning were based on the so-called solo-learner model, and the opportunities to individualise learning processes were supposed to be the crucial feature of computers. This was especially true for CAI-programs based on the ideas of programmed instruction, but the emphasis of individualistic models was also typical of many learning environments designed according to constructivist principles (Crook, 1994). It was particularly the omission of social interaction in computer-based learning environments which worried many educators in the eighties (Baker, 1985; Cuban, 1986; Hawkins, Sheingold, Gearhart & Berger, 1982; Isenberg, 1992; Kreuger, Karger & Barwick, 1989; Turkle, 1984).

During the last ten years, the situation has changed dramatically. Most of the recent research on the use of information and communication technology in education is more or less explicitly considering technology’s possibilities to facilitate social interaction between teacher and students, and among students. Collaboration and communication is certainly a main idea in network-based learning environments but social interaction has also been more and more taken into consideration in the design and implementation of systems running in separate workstations (see several chapters in Vosniadou et al., 1996).

There are two research traditions which have powerfully contributed to the development of the ideas of computer-supported collaborative learning. The first source is cooperative learning, which was an important element already in the programmes of progressive pedagogics from the beginning of this century. According to Slavin (1997; see also Damon & Phelps, 1989), research on cooperative learning can be considered as one of the greatest success stories in the history of educational research. The amount and quality of that research greatly accelerated in the early 1970's and is currently one of the most expanding topics in educational research. Numerous studies have compared cooperative learning to traditional teacher-centered studies and several theories have been presented to explain the mechanisms behind the observed gains in achievement.

The other source of inspiration for developing computer-supported collaborative learning originates from the research on Computer-Supported Collaborative/ Cooperative Work (CSCW). This research has revealed many issues about the cooperative nature of work in the computerised work context (Baskerville & al.1995; Tuomisto, 1994). Some of the theoretical ideas and computer tools used in CSCL environments have originally been created and elaborated in modern work contexts.

In this review, we briefly summarise the main findings of the Computer-Supported Collaborative Work and Cooperative Learning traditions that have proved to be important in developing CSCL environments.

Research on Computer-Supported Collaborative Work

It is widely believed that work in organisations is increasingly becoming centred on collaborative work in groups. At least two types of arguments for deeper collaboration have been presented. From the organisation theory point of view, collaboration "is a principle-based process of working together that produces trust, integrity and break-through results by building true consensus, ownership and alignment" (Marshall, 1995). The distributed expertise point of view stresses more the cognitive demands of modern work which makes the collaboration and networking of different expertises necessary for successful problem-solving (Engeström, et al. 1997). For example, Schrage (1990) defines collaboration as "the process of shared creation: two or more individuals with complementary skills interacting to create a shared understanding" (p. 40). The distributed and shared expertise approaches emphasise that shared space is a fundamental requirement for the creation of shared understanding. That space then becomes a frame of reference for the collaboration and provides an environment in which collaboration can occur. Successful collaborative work also requires a culture of collaboration, supporting leadership, common vision, team processes, and information support systems.

Computer-Supported Collaborative Work is mainly based on "Groupware" which is information technology that provides the higher levels of coordination and cooperation needed to support individuals working together in organisations. Indeed. it has been suggested that groupware will lead to increased collaboration among individuals in organisations, in part through the creation of networks of shared spaces that facilitate common understanding and are fundamental to enabling people to collectively grasp key concepts and issues. Groupware is a relatively new term, first coined in 1978. According to Coleman (1997), the following definitions have been presented to characterise groupware:

?? Intentional group processes plus software to support them. (Peter and Trudy Johnson-Lenz)

?? A co-evolving human-tool system. (Doug Englebart)

?? Computer-mediated collaboration that increases the productivity or functionality of person-to-person processes (David Coleman)

Most of the groupware applications (eg. Lotus Notes®, Teamware ®, TeamFocus ®) support discussion databases, on the one hand, and, on the other, serve as a systems development platform on which highly structured database or workflow applications can be built. They enable a synchronous and asynchronous collaboration by introducing a measure of structure that facilitates the process of sharing, organising and navigating information through an interactive electronic space (Vandenbosch, Ginzberg, 1996/97). Desktop conferencing, videoconferencing, co-authoring features and applications, electronic mail and bulletin boards, meeting support systems, voice applications, workflow systems, and group calendars are key examples of groupware (Grudin, 1991). In addition to the common features, different applications provide users with different tools and functions:

> For example, Lotus Notes ® lets users transform textual documents into databases, incorporating fields that can be searched and indexed, without the usual constraints of field and record length associated with normal databases. Beyond these database functions, an important feature of Lotus Notes is the integration of document databases with e-mail: E-mail messages can be forwarded onto the document databases, and information from document databases can be forwarded as e-mail messages. This provides an infrastructure that supports a fluid interaction between individuals and within groups. To organise entries in a database, Notes(R) supports a hierarchical categorisation scheme based on topics. A discussion topic can also have subtopics, resulting in headings and subheadings in the database (Schlack, 1991).

An other example of groupware is ICL's Teamware ® which is a fully modular program. Teamware 5.1 modules include:

?? Teamware Mail, with access to a variety of mail protocols, mailboxes with a flexible folder structure and a suite of programming interfaces to messaging services.

?? Forum -an electronic bulletin board system. Discussions can be closed, resumed and outlined.

?? Library - a document management system for storing and retrieving electronic documents.

?? Calendar - a time management tool which assists users to organise their time, in planning meetings and in booking shared resources.
(Coleman, 1997).

In the literature there has been enthusiasm about groupware technology's opportunity to increase positive collaboration in organisations by enabling the creation of community knowledge bases that may encourage organisations toward a more open sharing of ideas (see Vandenbosch, Ginzberg, 1996/97; Coleman, 1997; Hiltz & Turoff, 1993). Hiltz and Turoff (1993) found that the social connectivity of users who adopt a computer-mediated communication system increased notably. They also found a strong tendency toward more equal participation, and that more opinions tended to be asked for and offered.

The empirical experiences do not, however, fully suppor this desire (Davenport, 1996). In her research, Orlikowski (1992) found that the organisation's culture and the users' understanding of the technology have an impact on the degree to which a groupware technology affects collaboration among group members. User do not have an appropriate framework for understanding how groupware technology differs from other, more familiar technologies (e.g., spreadsheets or e-mail) and this prevents them from taking advantage of the new technology's true potential. Jonathan Grudin presents a list of challenges that groupware designers should be able to cope with. The selected challenges given below are also adequate when we consider the planning of tools for computer-supported collaborative learning:

(a) *The disparity between who does the work and who gets the benefit.* A groupware application never provides precisely the same benefit to every group member. Costs and benefits depend on preferences, prior experience, roles, and assignments. A groupware application is expected to provide a collective benefit, but some people must adjust more than others. Ideally, everyone benefits individually, even if some benefit more; however, this ideal is rarely realized. Most groupware requires some people to do additional work to enter or process information that the application requires or produces.

(b) *Critical mass of users.* Most groupware is only useful if a high percentage of group members use it. Different individuals may choose to use different word processors but two co-authors must agree to use the same co-authoring tool! Achieving a "critical mass" of users is essential for communication systems. Even one or two defections may cause problems for meeting scheduling, decision support, or project management applications. Even in an idealized situation in which every individual will benefit once critical mass is achieved, the early adopters may well abandon it before the critical mass of users is reached.

(c) *Social and motivational factors*. Groupware may be resisted if it interferes with the subtle and complex social dynamics that are common to groups. The computer is happiest in a world of explicit, concrete information. Central to group activity, however, are social, motivational, political and economic factors that are rarely explicit or stable. Often unconsciously, our actions are guided by social conventions and by our awareness of the personalities and priorities of people around us, knowledge not available to the computer.

(d) *Exception handling in workgroups.* Work processes can usually be described in two ways: the way things are supposed to work and the way they do work. Software designed to support standard procedures can be too brittle. A passive strike tactic is to bring production to a halt by "working to rule" or "doing things by the book"; this has implications for groupware. A wide range of error handling, exception handling, and improvisation are characteristic of human activity. People know when the "spirit of the law" takes precedence over the "letter of the law."

(e) *Designing for infrequently used features*. We exaggerate the importance and frequency of the objects and events that we focus on. But many organizations are structured and responsibilities are divided in order to *minimize* the overall communication requirements and social interdependencies. As is well known, an increase in size can lead to a decrease in efficiency by increasing the communication and coordination overhead. Work has important social elements that can use support, but groupware features will be used less frequently than many features supporting individual activity.

Problems in implementing Computer-Supported Collaborative Work do not always originate from the shortcomings of the applied groupware. Orlikowski (1992) points out that the basically competitive nature of the organisation's culture limited interest in a technology to support collaboration. In the review of several field studies on CSCW, Kiely (1993) concluded that the use of groupware is able to enhance collaboration only in organisations that have an inherently collaborative culture.

In their review of the impact of groupware, Vandenbosch and Ginzberg (1996/97) concluded that these technologies will enhance collaboration in an organisation when: (1) organization members have a need to collaborate; (2) users understand the technology and how it can support collaboration; (3) the organisation provides appropriate support for the adoption, implementation, and continued use of the technology; and (4) the organisational culture supports collaboration. Lotus Notes ® and similar systems will, most likely, develop into an important component of groupware technology. However, it will not magically transform organisations from collections of highly competitive loners to well-integrated, cooperative groups of collaborators. Without careful planning for its introduction and the changes that this will entail, the impact of collaborative a computer system is likely to be quite limited. Successful implementation of collaboration technologies will require both a careful assessment of the fit of the technology to the organisation and a well-designed training program to introduce this new technology and its potential to the organisation members . (Vandenbosch & Ginzberg, 1996/97)

Cooperative Learning research

Both field studies and laboratory studies of the achievement effects of cooperative learning have taken place in every major subject, at all grade levels. As a result of this research there is a growing consensus among researchers about the positive effects of cooperative learning on student achievement (Slavin, 1997; 1995). There are, however, still many open questions and much disagreement about why cooperative learning methods affect achievement and, even more importantly, under what conditions cooperative learning has these effects (Slavin, 1997; Webb & Palincsar, 1996). Cooperative or group learning refers to instructional methods whereby students are encouraged or required to work together on learning tasks. It is widely agreed that we should distinguish cooperative learning from the traditional 'direct transfer' model in which the instructor is assumed to be the distributor of knowledge and skills. Unlike the teacher-centered models the principles of cooperative learning are based upon a learner-centered model that treats the learner as an active participant. The conversation, multiple perspectives, and argument that arise in cooperative groups may explain why collaborative groups facilitate greater cognitive development than the same individuals achieve when working alone (Harasim, 1997).

There are, however, important differences among various theoretical and practical understandings of collaborative learning (Damon & Phelps, 1989; Slavin, 1992). In particular, there are researchers who emphasise the changes in motivation structure brought about by certain forms of cooperative learning, while others hold that changes in task structure are all that are required to enhance learning. Because applications of cooperative learning typically change many aspects of both motivation and task structures, it is difficult to find any single theoretical explanation for the observed effects on achievement.

Slavin (1997) has presented four major theoretical perspectives aimed at explaining the achievement effects of cooperative learning: motivational, social cohesion, developmental, and cognitive elaboration perspectives.

Motivational Perspectives

Motivational perspectives focus primarily on the reward or goal structures under which students operate. From a motivationalist perspective, cooperative incentive structures create a situation in which the only way group members can attain their own personal goals is if all the members of the group are successful. In these conditions, group members must both help their group mates to do whatever helps the group to succeed, and to encourage their group mates to exert maximum efforts. Evidence from practical applications of cooperative learning in elementary and secondary schools supports the motivationalist position that group rewards are essential for the effectiveness of cooperative learning. Out of sixty-four studies on cooperative learning methods that provided group rewards based on the sum of group members' individual learning, fifty (78%) found significantly positive effects on achievement, and none found negative effects (Slavin, 1995).

Social Cohesion Perspectives

This theoretical perspective is related to the motivational viewpoint. According to this approach, effects of cooperative learning on achievement are mediated by the cohesiveness of the group. Also this perspective emphasises primarily motivational rather than cognitive explanations for the instructional effectiveness of cooperative learning. There is, however, an important difference. Motivational theory stresses extrinsic rewards: students help their group mates learn because it is in their own interests to do so. Social cohesion theorists, in contrast, emphasise the idea that students help their group mates learn because they care about the group. The social cohesion perspective emphasises teambuilding activities in preparation for cooperative learning, as well as group self-evaluation, instead of external incentives and individual accountability. A well-known application of this theory is Aronson’s (Aronson, Blaney, Srephan, Sikes, & Snapp, 1978) Jigsaw method, where students concentrate on different topics in "expert groups" and subsequently share their expertise in groups where students from all expert groups come together. The theoretical idea in the Jigsaw method is to create interdependence between the group members in a way that would increase social cohesion. A similar method has also been developed by Johnson and Johnson (1992) and the ideas have been applied in the instructional programme called Fostering Community of Learners (FCL), developed by Brown and Cambione (1994; 1996). The method of Brown and Cambione, which besides Jigsaw includes also many other innovative learning environment features, has proved to be effective particularly in improving higher order learning in students. This has, however, not been the case in all experiments based on the Social Cohesion theory. According to Slavin’s (1995) review, research on pedagogical applications of the Jigsaw has not generally found positive effects on student achievement. A typical problem with this method is that students do not necessarily get acquainted with material other than that which they have studied themselves. Some of the very well implemented applications of the Jigsaw method, however, indicate that it is possible to avoid this problem (Sharan & Shachar, 1988; Sharan & Sharan, 1992; Johnson & Johnson, 1994).

Developmental Perspectives

The third perspective for explaining the mechanisms of cooperative learning proposed by Slavin (1997) was developmental theory (see e.g. Murray, 1983). The fundamental assumption of the developmental perspective on cooperative learning is that interaction among children around appropriate tasks increases their mastery of critical concepts (Damon, 1984). Both major traditions of developmental psychology, the Vygotskyan and the Piagetian, have substantially contributed to the theory of collaborative learning. Although Vygotsky (e.g. 1934/1994;1935/1994) in general did not believe in the usefulness of spontaneous cooperation among children of the same age, his theoretical ideas have been widely used in later theories of cooperative learning. Particularly Vygotsky's (1978) idea of the zone of proximal development has been useful for understanding mechanisms in collaborative learning. According to this view, collaborative activity among children promotes growth if children of similar ages have developmental differences. More advanced peers are likely to be operating within one another's proximal zones of development, modelling in the collaborative group behaviours more advanced than those they could perform as individuals. Piaget (1926) held that social-arbitrary knowledge -- language, values, rules, morality, and symbol systems -- can only be learned in interactions with others. Peer interaction is also important in logical-mathematical thought in disequilibrating the child's egocentric conceptualisations and in the provision of feedback to the child about the validity of logical constructions. On the basis of Piaget's theory a group of psychologists undertook a systematic empirical investigation of how social interaction affects individual cognitive development (cf. Doise & Mugny, 1984). These researchers borrowed from the Piagetian perspective its structural framework and the major concepts which were used to account for development: conflict and the coordination of points of view (centrations) (Dillenbourg, Baker, Blaye, & O'Malley, 1996).

Cognitive Elaboration Perspectives

Cognitive Elaboration means a theoretical perspective in which cooperative learning is assumed to be effective because it requires participants to elaborate their cognitive structures in a social context. One of the most effective means of elaboration is explaining the material to someone else. Several studies on peer tutoring have found achievement benefits for the tutor as well as the tutee (Devin-Sheehan, Feldman, & Allen, 1976). Webb (1989, 1992) found that the students who gained the most from cooperative activities were those who provided elaborated explanations to others.

The cognitive elaboration idea of cooperative learning has been successfully applied in writing process models (Graves, 1983), in which students work in peer response groups or form partnerships to help one another draft, revise, and edit compositions. The well known Reciprocal Teaching model developed by Palincsar and Brown (1984) can also be considered as an example of the cognitive elaboration perspective. In Reciprocal Teaching, cooperative learning is a method for teaching reading comprehension skills. In this technique, students are taught to formulate questions for one another about a text. Students have to process the material themselves and learn how to focus on the essential elements of the reading passages before they are able to do comprehension modelling. Studies of Reciprocal Teaching have supported its effects on student achievement (Järvelä, 1996).

All four perspectives described above have somehow been considered in the current applications of computer-supported collaborative learning. The research tradition on cooperative learning has, however, been rather empirically oriented. Recent research on the role of collaboration in learning has tried to find deeper theoretical frameworks that could better guide the development of technology-aided learning environments.

From cooperative learning to collaborative inquiry and

knowledge building

Many authors agree that it is meaningful to make a distinction between cooperation and collaboration (Dillenbourg, Baker, Blaye, & O'Malley, 1996; Roschelle & Teasley, in press). The distinction is based on different ideas of the role and participation of individual members in the activity. Cooperative work is accomplished by the division of labour among the participants. It is an activity where each person is responsible for a portion of the problem solving, whereas collaboration involves the mutual engagement of participants in a coordinated effort to solve the problem together." (Roschelle & Teasley, in press).

Traditionally, cognitive theories have examined inquiry as an individual and mental process. As a consequence, cognitive theories have focused on analysing how an individual agent processes mental representations. Scientific thinking has traditionally been seen as a characteristic of an individual mind. However, in explaining human intelligent activity, both cognitive theory and the current philosophy of science increasingly emphasise the socially distributed (or shared) nature of cognition (cf., Hutchins, 1991; 1995; Oatley, 1991; Pea, 1993; Perkins, 1993; Resnick, 1991; Resnick, Säljö & Pontecorvo, 1997; Salomon, 1993; see also Kitcher, 1990; 1993). Distributed cognition refers to a process in which cognitive resources are shared socially in order to extend individual cognitive resources or to accomplish something that an individual agent could not achieve alone. Human cognitive achievements are based on a process in which an agent’s cognitive processes and the objects and constraints of the world reciprocally affect each other. Cognitive processes can be distributed between humans and machines (physically distributed cognition, Norman, 1993; Perkins, 1993) or between cognitive agents (socially distributed cognition). Salomon (1993, p. 112) has pointed out that distributed cognition forms systems that consist of an individual agent, his or her peers, teachers, and socio-culturally formed cognitive tools.

The cognitive significance of distributed cognition is based on the fact that human beings have only limited cognitive resources such as time, memory, or computational power (Cherniak, 1986; Harman, 1986). Norman (1993, p. 43) argued that human cognitive resources are highly overestimated; without external aids humans have only a limited memory and reasoning capacity. Higher cognitive accomplishments presuppose that an agent uses the external world and his or her fellow inquirers as sources of knowledge, organisers of activity, and in general as extensions of his or her cognition. A critical condition for a successful process of inquiry is the adoption of socio-culturally developed cognitive tools or artifacts (Resnick, Säljö & Pontecorvo, 1997). By using cognitive tools, multiple forms of representation, and other artifacts, inquirers are able to reduce the cognitive processing load and take on more complicated problems to solve than would otherwise be possible (Pea, 1993; Salomon, Perkins, & Globerson, 1991). Scientific thinking does not happen only in the mental plane, but requires different kinds of vehicles of externalisation, as anthropological studies in scientific laboratories have revealed (e.g., Latour & Woolgar, 1979; Latour, 1988).

In the background to theories concerning socially distributed cognition there are observations according to which many cognitive problems, which cannot be solved individually, can be addressed by combining the limited knowledge and skills of several agents (Forman & Cazden, 1985; Hatano & Inagaki, 1991; Hutchins, 1995; Miyake, 1986; Norman, 1993; Oatley, 1991; Roschelle, 1992; Scardamalia & Bereiter, 1989). A fundamental source of advancement of inquiry is social communication and, in the context of science, scientific argumentation. Mead (1932/1977) and Vygotsky (19341978) have argued that the basic mechanism of cognitive growth is communicative in nature; it is based on the 'resultant' of a communicative act in the case of Mead and on the Zone of Proximal Development in Vygotsky's (1978) framework. Through social interaction, the contradictions, inconsistencies and limitations of an agent’s explanations become available because it forces the agent to perceive his or her conceptualisations from different points of view. Limited cognitive resources can be overcome by distributing the cognitive load to several agents, each of whom is equipped with a restricted power of cognition. Externalisation is an important prerequisite for socially distributed cognitive achievements: as a part of objective knowledge, externalised conceptions can be compared with the conceptions of the others; thereby a way is opened to an agent’s Zone of Proximal Development (Vygotsky, 1978).

Cognitive research on peer interaction indicates that socio-cognitive conflicts emerging in interaction situations facilitate cognitive performances superior to those of the individual (Mugny & Doise, 1978; Piaget, 1980; Pontecorvo, 1982). Pairs of subjects tend to perform better than subjects working alone. Moreover, collaboration fosters the learning process of both less and more advanced students. Doise and Mugny (1984) argued that the learning process is more progressive when children with different cognitive strategies work together and engage in conflictual interaction.

Although it is generally acknowledged that collaboration is a very important cognitive and motivational force required for fostering conceptual advancement (see, for example, Miyake, 1986; Forman & Cazden, 1985; Roschelle, 1992), there is a controversy concerning whether the interaction needs to be conflictual. Hewson and Hewson (1984) argued that the emergence of a cognitive conflict does not guarantee conceptual advancement because it may be taken as a paradox and resolved by ignoring one of the conflicting elements. In his study on socio-cognitive conflict Lehtinen (1984) showed that the motivational and cognitive effects of a socially induced conflict are mediated by a very complex system of situational and personal factors. A study carried out by Chan, Burtis and Bereiter (1997) indicated that a cognitive conflict facilitated conceptual advancement on the condition that it was connected with active processing of knowledge. What was haracteristic of knowledge building activity was taking conflicting information as problematic, something that needs to be explained (Bereiter & Scardamalia, 1993). In addition, it may be plausible to assume that mere epistemic curiosity or puzzlement might fuel a need for epistemic change.

Miyake (1986) and Hutchins (1995) have argued that social interaction (and interaction with the tools of technological culture) provides new cognitive resources for human cognitive accomplishment. According to Miyake’s analysis, understanding is iterative in nature, i.e. it emerges through a series of attempts to explain and understand the processes and mechanisms being investigated. In a shared problem-solving process, agents who have partial but different information about the problem in question both appear to improve their understanding through social interaction (see also Oatley, 1991; Brown & Palincsar, 1989). Miyake (1986) and Hutchins (1995) argued that the cognitive value of social interaction appears to be based on the fact that human beings cannot keep more that one complex hypothesis activated at a time. Although an agent does not have an easily accessible cognitive mechanism for testing his or her hypothesis, this testing process occurs naturally with pairs of agents working together. Similarly, research on self-explanation effects, mentioned above, has revealed that explaining problems to oneself fosters cognitive achievements. Hatano and Inakagi (1986, 1987, cf., Holyoak, 1991; Hatano & Inagaki, 1992) as well as Brown and Palincsar (1989; Brown, 1988; Bielaczyc & Brown, 1994), have argued, further, that deep conceptual understanding is also fostered through explaining a problem to other inquirers. In order to explain one's view to one's peers, an individual student has to cognitively commit himself or herself to some ideas, explicate his or her beliefs, as well as organise and reorganise his or her knowledge (Hatano & Inagaki, 1992). Through this kind of process, inadequacies of one's understanding tend to become more salient. Moreover, social interaction fosters the emergence of a more abstract conception than individual working (Schwartz, 1995). Therefore, distribution of a task among several agents has fundamental cognitive significance.

The cognitive value of externalisation in social interaction is based on a process of making internal processes of thought visible (Collins, Brown, & Holum, 1991; Lehtinen & Rui, 1997; Lehtinen & Repo, 1996; Pontecorvo, 1986; Scardamalia & Bereiter, 1989). From a cognitive point of view, it is particularly important to transform internal and hidden processes of inquiry into a public form in which they can be examined and imitated. Advancement of one's inquiry can be fostered by making metacognitive processes (e.g., comprehension monitoring), which cannot normally be observed, "overt, explicit, and concrete" (Brown & Palincsar, 1989, p. 417; Brown & Campione, 1996). Hence, it is plausible to assume that imitation of good cognitive practices and appropriation of more advanced processes of inquiry can be elicited by creating learning environments that mediate all stages of the process of inquiry, not just the end result. This, in turn, would allow students to become aware of their conceptual advancement as well as of changes in their practices of inquiry.

Pea (1994) argued that, through computer-supported collaborative transformative communication, learning can be fostered which facilitates new ways of thinking and inquiring in education. It seems that for purposes of transformative communication, written communication, combined with face-to-face communication, is more effective than face-to-face alone because it requires more extensive thinking processes (Woodruff & Brett, 1993; Lamon, 1992; Cohen, 1994

Theories of distributed cognition imply that the subject of cognitive growth is a community of inquirers or a socio-cultural system rather than an individual agent. Reciprocal relationships between the nature of the environment and the cognitive characteristics of an agent seem, to a great extent, to determine the nature of one's inquiry. The cognition of humans is adaptive in nature (see Anderson, 1990; Hutchins, 1995; Perkins, 1993; Scardamalia & Bereiter, 1996;): Cognitive agents have a propensity to adapt to their environments, and, therefore, many characteristics of cognitive activity can be explained by analysing the structure and functions of the environment rather than the mental capacities of the individual agents involved. The nature of the environment of cognitive activity and the corresponding cultural practices structure and shape cognitive activity.

From the pragmatic constraints on human cognition it follows that an agent attempts to adapt to his or her environment with limited cognitive resources. The goals of an agent and the context of cognitive activity determine how these resources are allocated between different cognitive tasks. All cognitive acts have their costs, and engagement with complex and reflective cognition especially requires a great deal of cognitive effort (Perkins, 1993). Therefore, it is not rational to use more than a "sufficient" amount of cognitive effort to carry out one’s cognitive tasks. Examination of this "economy of inquiry" had a central role in C. S. Peirce's (1955; 1957; see also Delaney, 1993; Misak, 1990; Rescher, 1978) pragmatic theory of inquiry.

Adaptive cognition provides an economical explanation for the generality of cognitive strategies that are non-optimal from a cognitive viewpoint, but appear to represent purposeful and useful adaptation to local conditions of the environment (Perkins, 1993; Bereiter & Scardamalia, 1996). Current educational practices do not usually make deepening conceptual understanding an "epistemologically desirable" (Cherniak, 1986) alternative. Traditional learning environments allow a student to manage and even succeed without engaging in an extensive process of thought. Participation in higher-level processes of inquiry tends to require, in traditional learning environments, cognitive efforts very much above what is needed for doing well at school (see Scardamalia & Bereiter, 1996). As a consequence, adaptation in current learning environments usually does not tend to elicit reflective thinking, complex cognition or higher-level inquiry (see Norman, 1993; Perkins, 1992; Scardamalia & Bereiter, 1996).

There is evidence that certain environments facilitate adaptation through developing new cognitive competencies and higher-level expertise (Bereiter & Scardamalia, 1993). One may distinguish between first- and second-order environments. First-order environments are static in nature, and adaptation in these environments is oriented toward meeting a fixed set of conditions. In the second-order environments, by contrast, conditions to which an agent has to adapt change dynamically as a function of other people’s progress in the environment (Bereiter & Scadamalia, 1993). Scientific research communities represent this kind of second-order environment that sets up progressively changing requirements. A community that sets up gradually tightening requirements for an agent as well as provides support for higher-level accomplishments when needed, facilitates the dynamic development of one’s expertise. A very important condition for the development of expertise is to go beyond the current level of accomplishment by continuously taking on more challenging problems to solve as accumulation of experience decreases cognitive processing load (Bereiter & Scardamalia, 1993). The soocial community could provide strong support for progressive problem solving, i.e. facilitate agents’ working continuously at the edge of their competence, a practice critical for the development of adaptive expertise.

There is a growing body of evidence that cognitive diversity and distribution of expertise promote knowledge advancement and cognitive growth. Kitcher (1989; 1993; Dunbar, 1995) has shown that cognitive division of labour is an important prerequisite for the advancement of science. Distribution of cognitive efforts allows the community to be more flexible and achieve better results than otherwise would be possible. Moreover, studies by Hutchins (1991; 1995) and Dunbar (1995) revealed that groups which consist of members with different but partially overlapping expertise were more effective and innovative than groups with homogeneous expertise. New pedagogical models as well as technology-based learning environments are emerging that are grounded on distributed expertise and which utilise cognitive diversity. Fostering Communities of Learning approach developed by Brown and Campione (1994; 1996) is a pedagogical model that is designed to take advantage of the distributed expertise and cognitive diversity characteristic of communities of scientific practice. The approach is focused on adopting the goals, values, beliefs, and forms of discourse characteristic of scientific practice. Conceptual advancement is facilitated by cultivating each student’s own expertise. Students engage in a self-regulated and collaborative inquiry being responsible for the task as a group. The students are guided to monitor the progress of their distributed inquiry themselves. Social support for deepening inquiry could provide overlapping zones of proximal development (Vygotsky, 1978) in which students can operate at the edge of their competence (Brown & Campione, 1996). By collaborating with their peers and relying on powerful cognitive artifacts, participants are able to go beyond their current level of cognitive accomplishment.

Theories of distributed cognition imply that socio-cultural cognitive systems have cognitive and epistemic characteristics different from those of individual agents (Hutchins, 1995). In order to facilitate the development of higher-level processes of inquiry characteristic of scientific research, classroom practices should be restructured by imitating practices of scientific research communities rather than teaching scientific thinking skills as such (Bereiter & Scardamalia, 1989, 1994; Brown & Campione, 1996; Carey & Smith, 1995). All components of knowledge-seeking inquiry, such as setting up goals, research questions, explanations or search for scientific information, can be shared or distributed between inquirers. A technologically sophisticated collaborative learning environment designed by following cognitive principles could provide advanced support for this kind of distributed process of inquiry, facilitating advancement of a learning community's knowledge as well as transformation of the participants' epistemic states through a socially distributed process of inquiry. A collaborative process of inquiry in the new learning environments seems to have the potential to elicit some characteristics of the second-order environments, particularly to encourage students to work at the edge of their competence rather than rely on routine problem solving, and, thereby, create new conditions of cognitive adaptation at school.

The analysis, thus far, has revealed that human cognition is a socially distributed process in nature. However, a cognitive theory focused on explaining dynamic changes in human cognitive activity cannot manage without referring to changed individual cognition. According to a dynamic interaction view, individual and distributed cognition are in interaction and reciprocally affect each other (Salomon, 1993; Salomon et al., 1991). Salomon et al. (1991) have argued that distributed cognitive processes produce "cognitive residues" by enhancing an agent's cognitive competencies which affect subsequent distributed activities.

Perkins (1993) has emphasised the importance of individual cognition in distributed cognitive processes because epistemological or higher-order knowledge is nowhere represented in a distributed cognitive system. He argued that epistemological knowledge, such as knowledge concerning strategies of inquiry, patterns of explanation, and forms of justification cannot become distributed because it is continuously needed for executing complex processes of inquiry. Many weaker students have inadequate higher-order knowledge needed for regulating their process of inquiry in different domains of knowledge (Perkins, 1993; Perkins & Simmons, 1988). Perkins (1993) has proposed that in order to overcome the cognitive processing load and participate in purposeful inquiry, epistemological knowledge should be in the person rather than physically downloaded. An optimal solution, however, would be to have the epistemological knowledge both in the person and physically downloaded. An important part of epistemological knowledge can be implemented in the design of a technology-supported learning environment and corresponding cognitive practices.

Even though inquiry cannot be grounded on any absolute presuppositions or truths (Rescher, 1978; Harman, 1986), one can evaluate how a revised theory is improved in comparison with its predecessors. Further, a socially distributed process of inquiry provides strong support for the development of the participants' metacognitive skills. Social interaction between participants forces them to consider their conceptions from the viewpoint of the others, and this facilitates a growing awareness of one's own knowledge and beliefs. Collaborative learning, in which thought processes are externalised in the form of public discourse provides an agent with access to other participants' processes of thought, thus supporting the development of the agent's metacognitive skills. A metacognitive environment provides structures and activities that foster monitoring of one's own and the other students' comprehension and reflect advancement of inquiry (Brown & Campione, 1996). Further, computer-supported collaborative learning appears to engage students to participate in in-depth inquiry over substantial periods of time and to provide socially distributed cognitive resources for comprehension monitoring and other metacognitive activities. Active participation in comprehensive activity may support not only advanced conceptual understanding, but also the emergence of new metacognitive beliefs about knowing, and particularly about the importance of understanding (Hatano & Inagaki, 1992).

RESEARCH ON COMPUTER SUPPORTED COLLABORATIVE LEARNING:

FINDINGS FROM THE RECENT LITERATURE

Tools for collaboration

A cooperative group does not automatically improve the construction of higher order cognitive skills and complex knowledge structures. In order to increase the possibilities for mutual understanding and task-related social interaction, interaction tools are needed that are adequately related both to the new concepts to be learned and to the previous experience and knowledge of the students (Katz & Lesgold, 1993). There should be flexible methods available for the students, to help them externalise their preliminary ideas and make their thinking processes transparent to other people. The tools available in an activity environment should permit students to follow one another's thinking processes even in situations where one is not able to argue verbally. Furthermore, the environment and the working methods should encourage students towards mutual reflection.

Different tools have been developed to facilitate students' cooperation and collaborative learning. Some of the computer applications have originally been planned to be used as tools for collaboration, but there are also many programs which have been found to be helpful for social interaction although originally planned for solo learners. There is no established way to classify the different CSCL tools. In this review we have made some basic distinctions based on the type of technological and pedagogical solutions. Many researchers (eg. Dede, 1996) have shown how very different technical applications can be used to facilitate collaborative and distributed teaching and learning, including special network applications for CSCL, different multimedia/hypermedia applications and experiential simulations. It is not only the features of the applied technology but especially the way of implementation of the technology which support student collaboration.

Crook (1996) has widely analysed how computers can facilitate collaborative learning in schools. He makes a distinction between interacting *around* and *through* computers. The first perspective stresses the use of computers as tools to facilitate face to face communication between student pairs or in a small group. According to Crook (1996, p.189-193), technology may, in these situations, be serving to support collaboration by providing students with something he calls points of shared reference. He claims that a traditional class room situation is too thinly resourced for successful collaboration. There are not enough available anchor points at which action and attention can be coordinated. The capabilities of computers can be used as mediating tools which help students to focus their attention on mutually shared objects (Järvelä, Bonk, Lehtinen & Hämäläinen, 1998). In Crook's (1996) distinction interacting through computers refers to the use of networks. Local area networks (LAN) and wide area networks (WAN) and the global version of the latter (Internet) provide education with a variety of mediating tools for collaboration (e-mail, electronic bulletin boards, conferencing systems, and specialized groupware).

Local workstation applications without network (interacting around computer)

Conventional single-user programs reapplied in a collaborative context

In many educational experiments computers have been used for facilitating face-to- face collaboration by the students. Although the traditional idea of the LOGO program developed by Papert (1980) was to give opportunities for the spontaneous construction processes in an individual student, many field experiments have stressed the importance of collaboration between students in these environments (Crook, 1994; Hawkins, Scheingold, Geahart & Berger, 1982). Hoyles and her collaborators have argued that it is just LOGO's capacity to encourage and facilitate students' collaboration which makes it an important pedagogical tool (Hoyles & Suhterland, 1989; Hoyles, Healey & Sutherland, 1991). The technical extension of the traditional LOGO called LegoLOGO, where Lego bricks robots can be controlled by LOGO programs, has been an especially promising tool for creating collaborative learning environments (eg. Eraut, 1995; Järvelä, 1996)

Many different program types like databases, spreadsheets, maths programs, programming languages, simulations, multimedia authoring tools, etc. have been successfully used as tools to promote collaborative and cooperative learning (Amigues & Agostinelli, 1992; Brush, 1997; Eraut, 1995; Lehtinen & Repo, 1996).

Applications with special interface for facilitating collaboration

Several supported learning environments have been developed where the tools and user interface of the program are particularly planned to support social interaction between students. Collins & Brown (1988) argued that it is possible to facilitate the learner's reflection with the help of programs (eg. ALGEBRALAND and GEOMETRY TUTOR) which somehow display the student's solution or learning paths on the screen. Later, many applications have used this idea in order to support students' reflection but also mutual interaction. These features are implemented for example in TAPS (Derry, 1990); HERON (Reusser, 1996); and ALEL (Lehtinen & Rui, 1996; Lehtinen, Hämäläinen & Mälkönen, 1998). TAPS and HERON are computer programs for teaching and learning mathematical problem-solving. One of the main features in both programs is a graphical interface which is planned to externalise the problem-solving process in diagram form. The interface of HERON has proved to be helpful for both individual reflection and collaborative problem-solving (Pauli, Reusser & Staub, 1997).

Lehtinen et al. (1998) reported very similar results from a series of experiments with ALEL program, which has been developed for teaching experimental research methodology and statistical inference for university students. ALEL is meant to be used in intermediate and advanced university courses on research methodology and statistics. In the ALEL environment, students plan and conduct theirown experiments in the simulated environment. When the students are planning and realising an experiment, the system generates, step by step, an external representation of the activity structure. This representation is displayed on the computer screen as a hierarchical tree diagram. Students create experimental designs by defining sequences of actions. Every action forms a node in the tree diagram, which describes the activity structure of the students while planning and fulfilling an experimental design. ALEL has proved to be a very successful tool for methodology courses. On the basis of observations of students' interaction processes, Lehtinen et al (Lehtinen & Rui, 1996; Lehtinen, Hämäläinen & Mälkönen, 1998) concluded that the effectiveness of ALEL is at least partly based on the program's ability to support task-related social interaction in a conceptually complex domain. Graphical representation of the students' own activity path can be used as a tool for collaborative reflection. By using the Probability Inquiry Environment (PIE), Enyedy, Vahey, and Gifford (1997) examined how external representations (both textual and iconic) mediate face-to-face conversations among students, and support productive discourse.

Collaborative reflection has also been applied in SHERLOCK which is a tool for training electricians to carry out an electronic troubleshooting system for F16 aircraft of the US Air Force. Sherlock-II provides a collaborative learning extension for Sherlock. After the student solves an electronic fault diagnosis problem in Sherlock-II, the system provides the student with the opportunity to reflect on the troubleshooting performance during a phase called *Reflective Follow Up*. Sherlock-II expects the students to elaborate upon their problem solving strategy, critiquing their own solutions, which entails explaining why an action is inappropriate or suboptimal and suggesting alternatives (Katz & Lesgold1993).

In many computer programs there are tools which are planned to organise the different role distributions and communication activities proposed in the theories of cooperative learning. Alavi (1994) has developed a computer-mediated collaborative learning environment where students work in teams. Student teams consisting of four individuals did group analyses of business cases. The teams followed the STAD collaborative learning procedures of Slavin (1987). They worked in the teaching theatre equipped with the Vision Quest program. The main features of Vision Quest´s Software Tools can be described as follows:

Software Tool	Software Tool Capability
Brainstorming	Generate ideas/alternatives
Comment card	Gather information (comments) about an issue/ alternatives
Compactor	Categorise ideas/ alternatives
Point Allocation	Distribute a specified number of points across all alternatives in a list
Ranking	Prioritise a list of ideas/ alternatives
Rating	Evaluate individual alternatives against criteria
Scoring	Rate alternatives against weighted multiple criter
Sub-group Selection	Select a predetermined number of alternatives frc
Voting	Yes, No voting on alternatives

Wang and Johnson (1994) have developed a Collaborative Learning And Research Environment CLARE which is meant to support the collaborative construction of knowledge from research papers. CLARE consists of two different tools: (1) A knowledge representation language called RESRA that serves as a meta-cognitive framework for understanding scientific research literature and the learner's perspectives. (2) A process model called SECAI that prescribes a systematic procedure to guide learners in interpreting knowledge elements. CLARE integrates RESRA and SECAI into a consistent, hypertext-based interface.

Similar ideas have been applied in many programs developed for different subject matter areas. AlgoArena (Kato et al. 1995; Suzuki, H. & Hiroshi, K. 1997) and the Design Studio of Shaffer (1997) are examples of two different areas. AlgoArena is a tool for the collaborative learning of programming by novices at the introductory level. This software aims to foster programming skills through collaborative programming activities in which learners are encouraged to cooperate or compete with others. The Design Studio is a tool for computer-supported collaboration in mathematics. In all these tools the computer is used in organising and supporting students face-to-face collaboration in a classroom situation.

A very special type of environments for collaborative learning has been developed by Dillenbourg and his collaborators. In these environments, students are provided with artificial social interaction partners. By using artificial intelligence technology, Pierre Dillenbourg and John A. Self (1992) have developed a human –computer collaborative learning system (PEOPLE POWER) in which a learner tries to solve problems in collaboration with the computerised co-learner. In this system, learners can later on "replay" the argumentation structures they have used in the interaction with the artificial co-learner and to use them as tools for reflection. The intended learning outcome is a structuring of knowledge or rules into situation-specific models, used to guide reasoning. Similar ideas have been applied in the MEMOLAB programme developed by Dillenbourg, Mendelsohn, and Schneider (1994), where the learning programme provides the student with several collaboration agents (coach, tutor, expert). While conducting simulated psychological experiments, students can collaborate with these artificial agents.

Network-based tools for collaborative learning (interacting through computer*)*

The rapid development and expansion of computer network technology has had a strong influence on the tools and methods of CSCL. Networks facilitate students' collaboration even in situations where there are no opportunities for face-to-face communication. When learning interaction takes place through computer networks it opens new possibilities but also causes some problems that do not exist in face-to-face communication. In a network-based environment, students and teacher can interact through the computer free of the limitations of time and place. Asynchronous and distance communication are new features of collaboration which challenge our pedagogical thinking. It makes more intensive collaboration possible with the out-of- school experts, brings students from different schools into contact with each other and creates powerful tools for joint writing and knowledge sharing. There are, however, different levels at which the network environment supports collaboration.

From a series of studies, Bonk & King, (1995) concluded that networks can: (1) change the way students and instructors interact; (2) enhance collaborative learning opportunities; (3) facilitate class discussion, and (4) move writing from solitary to more active, social learning. They also presented a taxonomy of different networks tools for learning environments from simple e-mail systems to rich collaborative hypermedia networks.

Local Area Network-based client-server systems

In the scientific community the CSILE system is considered a prototype of network-based collaborative learning environments. Besides CSILE there are several CSCL softwares based on local area networks and client-server architecture. Many systems are content-free, multipurpose environments which provide students and teachers with tools for communication, creation of joint documents etc. (Barker & Kemp 1990; Bump 1990; Butler & Kinneavy 1991; Faigley 1990; Havwisher & Selfe 1991; Newman, Johnson, Webb & Cochrane, 1997). In Butler's (1995) research on writing to learn history, high school students communicated with one another using a classroom local area network e-mail network system (Daedalus Mail) to share and discuss their research projects and a real time conference program (Daedalus InterChange) to conduct electronic discussions about historical figures and issues. McConnell's (1994) CSCL environment was made up primarily of computer conferencing and electronic mail (Caucus system), with access to online data bases and library catalogues.

The other type of tools is especially tailored for special purposes and certain subject domains. For example, the ThinkerTools program by Frederiksen and White focuses on the development of scientific inquiry strategies and skills and their use by students in developing and understanding science. Graves and Klawe (1997) created a Multi-media Activity Builder to allow a pair of players to build a house together, each working from their own computer. Work on the CSCL activity Builder has been done within the context of the E-GEMS (Electronic Games for Education in Maths and Science) group at the University of British Columbia.

E-mail as a tool for collaborative learning

E-mail has been a normal communication tool in universities and also in many schools for several years. In teaching, e-mail has served as a practical method to deliver actual information to students or to give personal supervision. It has also been used to support national and international communication between schools located far away from each other. Although the basic idea of e-mail is to serve as a tool for dyadic communication, it can also be used in larger collaboration. With the help of mailing lists, a larger group of students can use e-mail in sharing joint documents and in commenting on each other's work. The use of e-mail as a learning tool has dramatically increased particularly in university studies (Steeples, Goodyear, & Mellar, 1994). An e-mail-based learning environment can be used as a very open system for spontaneous collaboration or it can be more organised, controlled, and tutored (Ahern, Peck, & Laycock, 1992).

Marttunen (1994; in press a; in press b) has used the standard e-mail system in a series of experiments aimed at supporting the development of argumentation skills of university students. In these experiments, e-mail discussions were connected with individual reading processes. While reading different textbooks, students continuously participated in a spontaneous, strongly tutored e-mail conference with their study mates.

Besides standard e-mails software there are also many applications where an e-mail system has been extended with different features developed for educational purposes. KidCode by Baker, Levy Cohen and Moeller (1997) is an e-mail-based software designed to supplement the National Council of Teachers of Mathematics (NCTM) elementary curriculum standards by addressing the need to develop conceptual links between concrete mathematical activities and mathematics as a language.

Collaborative learning in the Internet and World Wide Web

The difference between elaborated e-mail systems and Internet-based conferencing systems is not very great. Conferencing has been available on the Internet for years in the form of Usenet newsgroups. When support for forms input was added to HTML, it opened the door to conferencing on the Web. Computer conferencing is an interactive medium that has existed since the first computer networks (Rheingold, 1993) but has only recently been implemented as a common resource for educational environments. It is similar to other forms of computer-mediated communication, such as e-mail lists, but it has special features like user-control, document structures, shared databases, and interaction style that make it an especially effective form of interaction for education (Bates, 1995; Harasim et al.,1995; Malikowski, 1998). One of the features of Web-based conferencing that can support an educationally relevant debate and online conversations is the efficient management of conversations. Other supporting features are time independence and location independence which allow a combination of synchronous and asynchronous discussions (Bates, 1995; Malikowski, 1998; Phelps et al., 1991).

World Wide Web -based environments for collaboration can be structured in very different ways. Many interactive www applications make it possible for the users to write their own comments in the document but offer little structure for the posted messages. Each new message is simply added after the previous messages. "In this sense, these Web pages resemble the early electronic bulletin board systems that began to pop up in the late seventies and early eighties. It is possible to write a message responding to an earlier posting, but since it is just tossed into a big pot along with unrelated messages, with no connection between the original message and the reply, it's difficult to carry on an extended conversation." (Woolley, 1995)

According to Woolley (1995), some structure is essential for a true conferencing system. In particular, the system must support something Woolley calls "threading," that means the ability to sequentially read the messages that make up one discussion. Several of the recently developed www-based conferencing systems offer such threading, but there are also examples of systems which are too strictly structured to be accepted by the majority of users. As an example of a strictly structured application, Woolley describes the WIT system developed by Ari Luotonen in 1994, which is one of the very first conferencing tools in www. In the WIT environment a discussion takes the form of a permanent, continuously expanding hierarchical tree. The tree can branch out indefinitely, but the top three levels of the hierarchy have specific purposes and are labelled accordingly:

?? Topic - an issue to be resolved

?? Proposal - a statement up for discussion, related to a topic

?? Argument - an argument for or against a proposal

Any participant can start new topics and write proposals or arguments. When a user enters WIT, he or she can see a welcoming message describing the purpose of the discussion area, followed by a list of topics. Selecting a topic takes the user to the page for that topic. "Topic, proposal, and argument pages all have a few things in common: a title, date, author's name, and text. They differ in what appears below the text, though. A topic page lists only the proposals associated with the topic. But a proposal page shows the entire tree of arguments branching off of the proposal. An icon next to each argument indicates its type: a white checkmark for an agreement, a red X for a disagreement. An argument page is similar to a proposal page, except that only the portion of the tree branching off of that particular argument is displayed." Woolley, 1995).

One problem noted by many WIT users was that each article is forced to either "agree" or "disagree." What if the user wants to add a pertinent comment that does neither? A similar problem appears if he or she agrees with some points of a proposal and not with others. Another problem is that every branch off a topic is labeled a "proposal." But some topics need to branch into subtopics rather than proposals. (Woolley, 1995)

Very many different ways to structure discussion into tree, star, etc. structures have been proposed in the numerous internet and www-based conferencing systems developed during the recent years. In his Web pages (updated May 5, 1998), Woolley listed about 150 conferencing systems available in the internet. Only a few of them like Virtual-U (Harasim, 1994; Harasim, Hiltz, Teles, &Turoff, 1995), WebCT (Goldberg, & Salari, 1997) and Interactive Learning Network (http://courses.lightlink. com/web/index.htm) have originally been created for educational purposes. However, many systems developed for computer conferencing in general like COW (http://thecity.sfsu.edu/COW2/) have been successfully applied in education.

Virtual-U, a virtual university is one of the first widely used www-based learning environments. It attempts to shape the www online environment to support collaborative learning, by special emphasis on architecture, campus spaces and tools. It is designed according to a spatial metaphor in which users navigate using images of university buildings, offices and study areas (Harasim, 1994; Harasim, Hiltz, Teles, &Turoff, 1995).

In the research literature, there are descriptions of several systems especially developed for various educational purposes. Bell (1997) has developed a system which, using argument representations, tries to make thinking visible for individuals and groups. The argumentation tool is one component of the Knowledge Integration Environment (KIE), an Internet-based learning suite for science education. It makes students thinking visible during individual and collaborative activities in the classroom.

JavaCap of Shabo et al (1997) is a www-based software tool for student authoring and searching of case libraries. Students will use JavaCap to publish what they have done and what they have learned and look up what others have published while they are solving problems. Web-SMILE developed by Puntambekar et al. (1997), is a resource for the Learning by Design -curriculum. It integrates synchronous and asynchronous collaboration and threaded discussion.

Creating and using shared databases is a feature which is somehow implemented in many of the network-based collaborative learning environments. Especially the rich supply of information services available in theWorld Wide Web makes the use of shared databases an attractive possibility. For exampl,e Kupperman, Wallace, & Bos, (1997) developed a learning environment in which students created and used a shared bibliographic database of resources which they found on the World Wide Web. In this experiment, ninth graders used a shared Internet database as a tool in collaborative research and knowledge building.

Combined multi-tool systems

In many applications students are provided simultaneously with a variety of tools aimed at supporting collaborative learning. In the study of Fishman and Gomez (1997), the classrooms were equipped with high-end Internet connectivity and computer-mediated communication (CMC) tools. Tools included e-mail, UseNET News, and an asynchrous multimedia tool called the CoVis collaboratory Notebook (see below for a more detailed description of the CoVis system) which is designed especially to support science inquiry. Sutton (1996) has planned a classroom for the Twenty-First Century in the DELTA project (Direct Electronic Learning Teaching Alternative), which has 3 goals: Improving instructional quality and effectiveness, increasing student access to higher education by making access more convenient and promoting greater productivity and accountability in the use of public funds. In this project the school is equipped with CalREN (California Research and Educational Network), a high bandwidth networks application, various instructional computers, video, slide projector, and overhead camera. Workstations are equipped with built-in video teleconferencing capabilities thus permitting geographically dispersed students to work collaboratively with full interaction.

Miller and Castellanos (1996) have also combined different tools in their study on the use of technology for science and mathematics collaborative learning: The Virtual Notebook System Trademark (VNS) and MATLAB. The VNS Trademark is a distributed multimedia hypertext system, with a "shared space" electronic notebook , where users create and share notebook pages.

Information is organised into objects like text, drawings, audio and video segments, animated images, links or real-time video-telecommunication links. MATLAB is a high performance programming language for scientific and engineering numeric computations.

In an Italian project, **TELECOMUNICANDO ti presento i miei tesori** (Using Telecommunication to present my goods), students (from 3rd to 12th grade) studied cultural features by developing a shared hypermedia. There was collaboration between different schools through telecommunication and videoconferences. The teachers were involved as researchers and the main aim was to evaluate metacognitive, motivational and social effects of collaborative learning (see below for a more detailed description of the project).

Effects of CSCL on learning and achievement

There is a long research tradition which has shown that cooperative and collaborative conditions are helpful for learning (Slavin, 1997). This is especially true in conditions where the division of labour and collective incentives emphasise the good achievement of all group members. Most of the effectiveness evidence of cooperative learning comes from short-term experiments and is based on rather mechanistic cognitive achievement. Theories of collaborative learning are based on the notion that knowledge construction is basically a social event, and adequate collaboration is particularly important for learning complex knowledge and higher order cognitive skills. One of the best known success stories of collaborative learning is the so-called reciprocal teaching developed by Palincsar and Brown (1984). This model has also proved to be successful in many later experiments using similar conditions (Järvelä, 1996). But what is the added value of computers in collaborative learning environments?

Large meta-analyses on the effectiveness of computers have shown that in the majority of experiments the use of technology has markedly improved the learning outcomes (e.g. Fletcher-Flinn & Gravatt, 1995; Khaili & Shashaani, 1994; Kulik & Kulik, 1991; Kulik, 1994). These studies do not, however, distinguish between different pedagogical ideas on how computers have been implemented in classrooms. Thus, it is impossible to draw any conclusions about the effectiveness of CSCL on the basis of these general impact studies.

Several empirical experiments offer some evidence that the well-known CSCL environments like CSILE and Belvedere have proved to be helpful for higher order social interaction and, subsequently, for better learning in terms of deep understanding (Scardamalia, Bereiter, & Lamon, 1994; Suthers, 1998). What is still lacking is the evidence that the same results could be achieved widely in normal classrooms. It is also possible that similar positive results could be reached in classrooms carrying out the same collaborative activities without computers.

Although hundreds of papers on CSCL have been published during the last few years there have not been too many well controlled experiments, which could answer the questions concerning the wider applicability of CSCL in normal classrooms, and the added value of computers and networks in comparison to collaborative learning environments without technology. Most of the publications we read for this review described the systems and conditions, as well as the students' conversation processes, but presented no data on the learning outcomes. One could argue that this is because of the different paradigm or metaphor of learning adopted in these studies.

Sfard (1998) has made a division into two main metaphors of learning: the acquisition metaphor and the participation metaphor. The questions concerning the learning outcomes belong to the more traditional acquisition paradigm which interprets learning in terms of the acquisition of something in an individual mind and knowledge in terms of property and possession. The ideas of collaborative learning at least partly belong to the emerging participation metaphor. According to this approach, it is not meaningful to ask how much or how well organised knowledge an individual student has acquired. Instead, this approach deals with learning as becoming a participant and with knowledge as an aspect of practice, discourse and activity (Sfard, 1998, 7).

There are numerous studies on CSCL environments demonstrating encouraging effects on the amount and quality of social interaction and other procedural features of teaching-learning processes (e.g. Amigues, & Agostinelli, 1992; Crook, 1994; Davis & Huttenlocher, 1995; Fishman J. & Gomez, 1997; Lamon et al., 1996; McConnell, 1994; Rysavy & Sales, 1991; Scardamalia, Bereiter & Lamon, 1994; Suzuki, & Hiroshi, 1997). Besides these optimistic "mainstream" papers there are also a couple of research reports which try to analyse also the shortages and problems students have when participating in CSCL learning environments. In particular the general passivity and uneven distribution of participation are common but seldom thoroughly analysed problems in collaborative learning environments (e.g. Eraut, 1995; Lehtinen, et al. 1997). When it concerns communication through computers, the constraints of social interaction are different from the face to face communication (Lea, 1992; Walther, Anderson & Park, 1994). These changes in communication are not sufficiently analysed in recent research on the interaction processes in CSCL.

We agree with Sfard (1998) that both of the two metaphors of learning (acquisition and participation) are needed. The acquisition approach should not be fully replaced by the emerging participation approach. This means that, besides the description of activities and discourse processes, we should also consider the knowledge acquisition of individual students in CSCL environments. However, it is important to notice that the attempt to infer direct causal relations between the use of a certain computer application and learning outcomes can be misleading. Salomon (1994; 1996) has strongly stressed this problem. He has suggested a more systemic approach, where the patterns of change should be analysed rather than simple causal effects between independent and dependent variables.

Rysavy and Sales (1991) published a review in which they summarised the results of 13 studies on cooperative computer-based instruction (published between 1982 and 1988). They discussed the findings related to achievement and motivation. In ten of these studies the achievement of students was explored. In six studies, the computer-based cooperative condition resulted in better learning results than in the control conditions, whereas in four studies there were no significant differences. Motivation was considered only in two studies and both reported positive effects. In the study of Hooper and Hannafin (1988), the achievement measures were also related to different ability groupings. According to their results, the achievement of low ability students was higher in heterogeneous groups than in homogenous groups. Six of the studies dealt with gender issues. In three researches (Carrier & Sales, 1987; Dalton, Hannafin & Hooper, 1987; Johnson, Johnson & Stanne, 1985) there was some evidence that computer-based cooperative learning was beneficial for female students. In three other studies, the gender-related differences were not significant.

The amount of studies on CSCL has dramatically increased during the last ten years. There have been numerous studies aimed at investigating the effects of CSCL on student achievement. Many studies on small group computer-based instruction, published in the late eighties and the early nineties, indicated at least some positive impact on students' learning (e.g. Anderson, Mayes and Kibby 1995; Hativa, 1988; Hooper, 1992; Mevarech, Silber, & Fine, 1991; Shlechter, 1990).

In their study in 1992, Light and co-workers conducted an experimental study, in which one hundred and twenty 11- and 12-year-olds worked on a computer-based problem-solving task couched in an adventure game format. The game was implemented in HyperCard 2 on the Macintosh computer. The scenario drew upon elements of a familiar children´s story/song and a contemporary TV advertisement aimed at children. The task was a specially designed computer-based route-planning task. As a result of this experiment, there was some significant advantage for pairs over the individual in the second session of the three sessions. However there was no advantage at individual post-test. Boys' results were slightly better. Performances of three different pair types (Boy-Boy, Girl-Girl and Boy-Girl) showed a trend: Boy-Boy> Boy-Girl> Girl-Girl. The trend was significant in all three sessions.

Light and co-workers have also reported studies on peer interaction (1995). In the first study there were 39 children (13 pairs, same sex, and 13 individuals). The task introduced an adventure game in an imaginary country. Most of the knowledge needed to devise the plan of action had to be discovered from the knowledge base. The previous knowledge which was assumed to be shared by all the subjects was minimal. The other study was a pilot experiment that involved 15 adults (5 individuals and 5 pairs). In both experiments, pairs exhibited more anticipatory planning by getting more information before beginning the execution phase. Pairs revealed themselves to be more effective in using prompts and revising their strategy when confronted with information such as error messages provided by the system.

All these impact studies described above dealt with face-to-face communication around computers. In the studies summarised in Table 1, there are also experiments where computers and networks are used as communication tools in distance and asynchronous interaction (interacting through computers).

Table 1. Effects of recent CSCL experiments

Authors	Tools	Subject	Participants	Effects
Alavi, M. 1994	Vision Quest´s Software: a tool for teamwork and collab. Know. Construction (WS)	Information systems manage-ment	127 MBA students	Significant experimen subject learning affect perceived skills, self re learning and interests
Baker, Levy Cohen, & Moeller, 1997	(KidCode) e-mail-based software/ mathematical	Mathematics	20 children (ages 5-10)	Improvement in childr competence with symb

	representation tools (WAN)			processing*
Bell, P. 1997.	(KIE) Internet-based learning suite: argumen-tation tools (WAN)	Physical science	180 middle school students	Progress in use of con
Bruckman, & De Bonte, 1997	Text-based virtual reality environment (WS)	Reading, writing and computer-programming	3rd-6th. graders, N=?	positive impact on the
Brush, 1997	ILS (Integrated Learning Systems) used by individuals and groups (WS)	mathematics	65 fifth-grade students	Students in groups sho significantly positive a created higher order q individuals
Butler, 1995	Daedalus Mail and InterChange, a conference system (LAN)	History	45 high-school students and peer tutors (university students)	students' learning and toward writing and the history improved*
Chyung, Repman, & Lan, (1995).	Academic Risk-taking (ART) math computation task (WS)	Mathematics	75 third grade and 62 fourth grade students	CSCL students took si higher risks (selected r problems)
Enyedy., Vahey,. & Gifford, 1997	Probability Inquiry Envi-ronment (PIE) (WS)	Mathematics	7th graders (PIE gr. n=45, contr. Gr.=54)	Significant experimen math tasks
Graves, D. & Klawe, M. 1997	A multi-media tool (Builder) for student pairs (WS)	Mathematics	134 element. school children, 10-12 years old	significant experiment math tasks/ positive att
Hmelo, Vanegas, Realff, Bras, Mulholland, Shikano, & Guzdial, (1995).	Collaborative Multimedia Interactive Learning Environment (CaMILE) for Problem Based learning (WAN)	Engineering	engineering students N=?	CSCL students were b examining the ethical, and economic issues b applying their knowled
				….Continues

Hooper, Temiyakarn & Williams, 1993	Computer program designed for experimental purposes	Artificial symbol system	175 fourth-grade students	High and average-abili significantly better in h learning and generalisa
Kupperman, Wallace, & Bos, 1997	World Wide Web-database (WAN)	Social science	82 high school students,	No anticipated effects
McConnell, D. 1994.	Computer conferencing and electronic mail (Caucus system) (LAN)	Management	2 year part-time university students N=?	Observed effective gro

Newman, Johnson, Webb & Cochrane (1997)	Network Telepathy computer conferencing system (WAN)	Information management	Undergraduate students	Face-to-face seminars creative problem explo computer conferencin elaboration and integra
Repman, J. 1993.	Unstructure, structured, structured collaboration with training in computer environment (WS)	Social studies	190 seventh grade students	Significant difference of thinking in favour o received collaboration
Shabo, Nagel, Guzdial, & Kolodner, 1997	JavaCap, tool for problem-based learning	Earth science/ life science	7 eighth graders, 14 seventh graders	Only process observat positive effects*
Seymour, 1994	Drawing software	Computer-aided drafting	57 university students	No significant differen cooperative and indivi structures
Silverman, Barry G. (1995).	Constructivist jigsaw with and without computer support (LAN)	Management	Adult, tertiary students	Computer-supported c students outperformed collaboration group

* no controlled experimental model

WAN = wide area network-based system

LAN = local area network-based system

WS = a single workstation based system without network

The studies presented in Table 1 support the theoretically derived hypotheses that collaboration facilitated with information and communication technology would improve student learning. Many of the studies are, however, short-term experiments focused on a small number of students. Some of the CSCL projects like CoVis (Pea, Edelson & Gomez, 1994a) are very widely spread, but well-controlled follow-up results of the methods are still missing. It is also important to notice the general problems of impact studies. Learning environment studies with positive effects have much better opportunities to be published than qualitatively equal studies with negative or no significant effects. In addition, the so-called control conditions are seldom as carefully planned as the experimental treatments (see Kulik & Kulik, 1987). Bearing in mind the above limitations, we can infer that it is possible to improve the quality of learning by using CSCL methods.

ADVANCES IN COMPUTER SUPPORTED

COLLABORATIVE LEARNING: A review of good practices

Several different models and technical tools have been developed for CSCL. There are some well known systems which have played an exceptional role in the development of the theory and practice of CSCL. In this chapter, we describe three of them, which in our opinion appear to be theoretically most interesting and which demonstrate partly complementary principles and practices. All the applications presented in this chapter have originally been developed for science education although some parts of them have later been used in other domains. The three learning environments are based on careful theoretical analyses.

Computer-Supported Intentional Learning - CSILE

Several important aspects of knowledge-seeking inquiry characteristic of scientific research outlined above are implemented in the structure of the Computer-supported Intentional Learning Environment, CSILE, and corresponding cognitive practices. The CSILE environment, developed originally in the late eighties (Scardamalia, Bereiter, McLean, Swallow, & Woodruff, 1989), is a networked learning environment for fostering higher-level processes of inquiry in elementary education. CSILE is an environment for building, articulating, exploring, and structuring knowledge (Scardamalia & Bereiter, 1989; 1990; 1991b; 1992a, 1993; 1994; 1996; Bereiter & Scardamalia, 1991).The design of CSILE is based on an ingenious application of recent research on expertise, literacy, collaborative cognition and complex problem solving. The system contains tools for text and chart processing, and a central part of the system is a communal database for producing, searching, classifying, and linking knowledge. In order to facilitate in-depth processing of knowledge, the students themselves are responsible for producing all knowledge in the database. The system facilitates the sharing of cognitive achievements by providing each student with access to all textnotes, comments and charts produced by their fellow students. CSILE is designed to foster collaborative learning through its advanced facilities for searching out and commenting on knowledge. Students use CSILE by writing notes, creating charts, and reading and commenting on each other's productions in the context of such domains of knowledge as mathematics, physics, biology, and history. CSILE is designed to provide facilitating structure and tools, i.e. procedural facilitation, that enable students to use their own thinking and knowledge (Scardamalia et al., 1989).

CSILE’s Thinking Types represent epistemological knowledge concerning critical aspects of inquiry that structure students’ cognitive activities without presupposing that the students themselves have epistemological awareness of the underlying principles.

Practices of working transformatively with knowledge are facilitated by CSILE through providing students with an environment for working together with knowledge objects (Scardamalia & Bereiter, 1994). By using Popper’s terminology (see Bereiter, 1994) CSILE students are guided to create world 3 objects by constructing their own intuitive theories. CSILE’s public database creates a sort of plane of objective knowledge, Popper’s world 3, for the classroom, a plane in which students can jointly work for advancing their communal knowledge. Students are engaged in productive working with knowledge objects in the same way as the scientific community is engaged in theory improvement. Scardamalia & Bereiter. (1994) argued that a very effective way of learning to understand and explain a knowledge object is to generate another object (e.g., hypothesis, theory) based on it.

The CSILE environment is designed to provide support for organizing a classroom to function like a collaborative scientific community. In order to examine how computer-supported collaborative learning fosters peer collaboration, it is important to analyze to what extent school children are able to create a culture of inquiry in which the building of knowledge is carried out collaboratively and each student's cognitive efforts to advance knowledge are socially supported. Critical questions are, for example, to what extent are students able to facilitate each other's conceptual understanding and whether discourse interaction between learners helps them to focus on productive lines of inquiry, search and share new information, and construct answers to their research questions (Scardamalia & Bereiter 1989).

CSILE is designed to engage students in an extensive process of setting up research questions, generating and improving their own intuitive explanations and searching for scientific information. Participation in all aspects of the process of knowledge-seeking inquiry is facilitated by the use of CSILE's Thinking Types. Moreover, a special kind of Thinking Type (INTU) facilitates articulation of new specific research questions and guides an agent to engage in deepening inquiry. Further, CSILE fosters socially distributed inquiry by providing tools for the sharing of cognitive achievements. The systems database facilitates objectification of knowledge, i.e., collaborative working for developing shared knowledge objects. The CSILE students' learning community is jointly responsible for their knowledge advancement. The system provides the users with advanced tools for communicating with the other members of the learning community. Thus, it seems that the CSILE environment has the potential to facilitate participation in higher-level practices of inquiry, as well as to create new conditions of adaptation at school.

In 1996 WebCSILE was developed, a tool that allows CSILE databases to be accessed by a normal web browser, such as Netscape or Microsoft Explorer. Web software does not offer the full range of features offered by the Macintosh client. It provides web-users with tools to read all database notes, to create new notes, and to collaborate with others using CSILE's commenting and discussion facilities (.http://csile.oise.on.ca/intro.html)

The commercial version of CSILE, called Knowledge Forum, was released in August, 1997. Knowledge Forum is a fully component-based knowledge-building environment. It builds on core CSILE technology and adds graphical functionality such as customizable views, scaffolds, build-ons, reader and new connection types. In Knowledge Forum there are 'Notes' that represent students' ideas and questions. In this environment, students 'build on' to notes, 'reference' others' work, make solicited 'contributions', 'rise-above' previous notes to create new syntheses, or make 'collections' of related notes. 'Scaffolds' are built in and provide support in areas such as text analysis, theory-building, and debating. Knowledge Forum is unique in that it offers multiple 'Views' on a growing body of knowledge. Views provide graphical organizers for notes. Notes can be added to one or more views, linked, placed in clusters, and moved to represent different ways of conceptualizing the developing knowledge base. It provides dynamic structuring facilities that extend well beyond typical list structures. These supports are designed to foster emergent goals and conceptual change (http://csile.oise.on.ca/intro.html).

Although several cognitive researchers (e.g., De Corte, 1993; Salomon, in press a; Salomon & Perkins, in press) have pointed out that many applications of educational technology support only lower-level processing of knowledge, computer-supported learning provide an exception. There is evidence that CSILE, in fact, facilitates higher-order cognitive processes and collaborative knowledge-building (see Lamon, Secules, Petrosino, Hackett, Bransford, & Goldman, 1996). Evaluations comparing CSILE and nonCSILE classrooms at the elementary level have shown significant advantages for CSILE on

?? Standardized test scores in reading comprehension, vocabulary, and spelling.

?? Ability to read difficult texts.

?? Quality of questions.

?? Depth of Explanation.

?? Math problem solving.

?? Portfolio commentaries.

?? Graphical literacy.

Hakkarainen (1998) analysed the qualitative effect of peer interaction in a CSILE environment on the inquiry process. The analysis indicated that the CSILE students shared their explanatory theories socially. Perhaps an even more important form of CSILE student communication that fostered deepening of each other's inquiry was the request for explicating explanatory relations. In these comments students pointed out that a student's note or theory was not comprehensive, and requested it to be made more understandable or articulated further. All the collaborative CSILE students and the teacher produced a large number of comments requesting explication of explanatory relations.

Hakkarainen and Lipponen (1998) compared children's inquiry and learning processes in different classrooms using CSILE in Canada and Finland. The results indicated that the differences between learning cultures have a strong influence on the ways in which the CSILE environment was embedded in the classroom practices. The researchers found two different classroom traditions which they called collaborative and traditional. The analysis indicated that there were substantial differences concerning the epistemological nature of inquiry between the collaborative and traditional CSILE groups. While the Collaborative group engaged increasingly from one year to the next in an explanation-oriented process of inquiry, the Traditional group continuously dealt with factual and descriptive information. Examination of both CSILE students' research questions and the knowledge produced by them revealed that the collaborative students' inquiry was more and more explicitly focused on generating their own explanation-seeking research questions and the construction of their own intuitive explanations, as well as searching for explanatory scientific information. Examination of the material indicates that the Collaborative group's extraordinary epistemic achievements presuppose a very strong engagement of the teacher; the conceptually challenging study projects could not have been carried out without the teachers' guidance. The teacher of the Collaborative group seemed to give the students a lot of epistemological support by providing an expert model of higher-level processes of inquiry.

Belvedere

The Belvedere system is based on the long-term research on computer-supported learning environments in the Learning Research and Development Center (LRDC) at the University of Pittsburgh (Lesgold, Weiner, & Suthers, 1995; Suthers, 1998; Suthers & Jones, 1997; Suthers, Erdosne, Toth, &Weiner 1997; Suthers & Weiner, 1995). Belvedere focuses and prompts students' cognitive activity by giving them a graphical language to express the steps of hypothesizing, data-gathering, and weighing of information. It provides apprenticeship in science by suggesting the next possible steps, and through cognitively motivated structuring of materials and activities. It supports collaborative learning through the shareability of diagrams by students in same-time same-place, same-time distant or asynchronous modes, as well as through text-based "chat" windows. Belvedere is based on a client-server architecture that can deliver advanced educational technology on a variety of platforms, requiring only that user machines run Java and have a few standard tools such as a Web-browser, a word processor and a spreadsheet.

The Belvedere application domain is learning critical inquiry skills, particularly in science. Suthers and Jones (1997) have summarised the basic actions of learning critical inquiry in science as follows:

?? Familiarising oneself with a field of study

?? Identifying a problem of interest

?? Proposing hypotheses (or solutions)

?? Identifying and seeking evidence that bears on these hypotheses (or solutions)

?? Drawing conclusions based on the evidence found

?? Summarising and reporting the inquiry to others

?? Evaluating the status of the inquiry, with repeat at any of the steps above

?? Discussing and coordinating the doing with others.

?? Obtaining solicited and unsolicited guidance on how to conduct critical inquiry

Belvedere's core functionality is a shared workspace for constructing "inquiry diagrams," which relate data and hypotheses by means of evidential relations. In the diagramming window a student can generate an "inquiry diagram", which is a graphical description of the arguments for and against a theoretical claim. When the students is working in the environment there is a window available for him or her displaying advice from a coach.

The architecture of the environment is based on a model describing the most crucial distinctions students have to acquire in order to conduct scientific inquiry. These activities are implemented in the program as separate tools available for the student. All the tools can be activated by the icons displayed in the interface. The icons are "data" for empirical statements, "hypothesis" for theoretical statements, "unspecified" shape statements about which students disagree or are uncertain; then links representing "against" and "for" evidential relations, and a link for conjunction. Students use the palette by clicking on an icon, typing some text (in the case of statements) and optionally setting other attributes, and then clicking in the diagram to place the statement or create the link. The other icons of the palette provide sources of counsel and knowledge: they are a light bulb representing "ideas" from the coach, an "in-box" that can receive information from Web pages, and icons that start other applications such as a Web browser. A "Guide" menu provides students with suggestions on how to use the software through five "phases of inquiry" (explore, hypothesize, investigate, evaluate, and report).

Diagrams provided by the interface are meant to support collaboration by providing a shared context and reference point. These advantages manifest in different ways depending on whether the students are co-present or collaborating over the network. When they are co-present, diagrams support collaboration by helping students keep track of and refer to ideas under discussion, whether using a single display, or two displays near each other. In these situations, students often use gestures on the display to indicate prior statements and relationships. In some groups, students work independently, then use gesturing on the display to re-coordinate their collaboration when one student finds relevant information. This can occur when information is brought to the group from off-line sources, such as hands-on experiments. Students can work in parallel on the same workspace, as long as they are not editing the same object at the same time. On networked computers, all changes are propagated to others working with the same diagram in a "what you see is what I see" manner. In addition to the diagram, a "chat" facility and a remote pointing mechanism support unstructured natural-language conversations, needed to coordinate the more structured inquiry diagramming when collaborating at a distance (Suthers, 1998).

There are no experimental data comparing the achievement results of Belvedere environment with the more traditional science classrooms. Instead, there are carefully conducted case studies of some experimental classes using Belvedere.

Belvedere was used by 5 teacher participants in 4 classes. The classes included 9th grade Science, and 9-12th grade Physics, Chemistry, and Science and Technology. During these classes, evaluation of the Belvedere classroom implementation was conducted by a third party evaluator representing the financier organisation of the project. The evaluation procedure made use of standard observation forms of the research programme as well as videotaped classroom sessions.

The independent evaluator's report discusses effects of the Belvedere approach on the general nature of student activity, on teacher roles and on the classroom environment.

Observations of student activity show that students were engaged and on task during the collaborative problem-solving situations presented to them by the Belvedere comprehensive approach. Teachers indicated that the approach enhanced students’ ability to engage in collaborative tasks.

> "Classroom observations of teachers and students using Belvedere show that it is being used to support cooperative problem solving, with students working in groups of 2 to 4 students. Students appeared to be engaged and on task. Teachers report that it is easy to use, and they find that it enhances students ability to

> engage in cooperative work, and to address scientific hypothesis testing in an organized and analytical way."

Students also found the activity structure easy to follow and helpful in integrating work with the use of various software tools and information resources such as the world wide web.

> "Students report that working with Belvedere makes it easier for them to organize and review the arguments for and against a specific scientific hypothesis. They also report that they find it easy to integrate work in Belvedere with work in other applications like Word and Excel and Web Browsers. Students using Belvedere generated artifacts that demonstrated integration of the knowledge representation maps generated using Belvedere with text and graphic information taken from a variety of resources, including the Internet, and with numerical data generated as a result of classroom activities."

Teachers reported that the staff development activities provided were adequate for classroom implementation of the Belvedere approach.

> "Data collected on the efficacy of staff development for teachers using Belvedere indicated that they were very satisfied with the training provided, and believed that they were well prepared to integrate use of the Belvedere software into their classrooms. The staff development provided for Belvedere compared very favorably with that provided by other application developers in the CAETI program.

The independent evaluator also reported a striking difference in classroom organization before and after the introduction of the Belvedere approach. The classroom changed from a traditional format, with students doing work at their desks in rows, to a group-centered organization, in which students were gathered around computers or hands-on activities "like campfires" and engaged in active discussion.

CoVis

Roy Pea and his co-workers have developed an instructional strategy for science education which also makes use of collaborative inquiry as the main method (Pea, Edelson & Gomez, 1994a; Pea, Edelson & Gomez, 1994b). Edelson, Pea and Gomez (1996) argue that the practice of science takes place mostly in communities, and relies increasingly on collaborations that span widely distributed institutions through the use of networking technologies to form "collaboratories". In developing collaborative learning environments, the CoVis project has taken technologies developed primarily to support collaboration in industrial and research settings and adapted them to high schools. These technologies enable students and others to work together within classrooms and across the country, at the same time (synchronously) or at different times (asynchronously).

The Learning Through Collaborative Visualization Project (CoVis) is engaged in research and development of new approaches to high school science education through collaborative project work with advanced networking technologies, collaborative software, and visualization tools. Through the use of advanced technologies, the CoVis Project is attempting to transform science learning to better resemble the authentic practice of science. In the first-ever educational use of wideband ISDN networks, high school students are enabled to join with other students at remote locations in collaborative work groups. Also through these networks, students communicate with university researchers and other scientific experts.

There are two kinds of tools implemented in the CoVis network. Scientific visualisation tools use graphics, images, colour and motion to present large quantities of data in a manner that allows the user to observe patterns in a large data set in the form of visual patterns in an image. The same tools used by professional scientists have been implemented in the CoVis environment as learning tools for students (Gomez, Gordin, Carlson, 1995; McGee & Pea, 1994). The collaborative software is designed to support students as they conduct scientific inquiries as members of acommunity. Also in the CoVis project, the idea is to bring the collaborative work typical of science practice into classrooms.

Students working in the CoVis environment use standard Internet tools (electronic mail, Usenet newsgroups, www) for information seeking and for communication with university researchers ant other scientific experts (Pea, Edelson & Comez, 1994). For mutual communication, students can use a collaborative application called CoVis Collaboratory Notebook (Edelson & O'Neil, 1994; Edelson, 1997). The Collaboratory Notebook is a groupware application especially planned for students collaboration in science projects. It provides a place for students to record their activities, observations, and hypotheses as they perform scientific inquiry. By using the Notebook, teachers and students can plan and track the progress of a project together. Students working in the environment can share and comment upon each other's work.

The Collaboratory Notebook is based on a structured hypermedia database. It consists of notebooks which can be private or shared among a group of collaborators. The table of content of the notebook displays the hierarchical organisation of the pages and which pages are related with each other. There are several types of links indicating different relationships between notebook pages. A question can be linked to a page where the students try to answer the question. In the answer page there can be links to the evidence for or against this claim. (Pea, Edelson & Gomez, 1994). By using these features of the Collaboratory Notebook, individual students and student groups can organise their scientific inquiry project.

Characteristic of the CoVis environment is that the collaboration tool is tightly integrated with the visualisation software. All the visualisation tools automatically generate a log of the whole experimenting process. A student can take a copy of the log and put it into the Collaboratory Notebook. Once the log is there, the student can annotate the log with comments and thus use it as a tool for reflection and collaboration .

There are about forty schools participating in the CoVis Project. According to the research plan of the project (http://www.covis.nwu.edu/info) the research on the CoVis learning environment is formative and iterative. The goal is to support inter-school projects in these forty schools. The CoVis research programmme has several parts focused on establishing and supporting inter-school learning communities. The parts of the research program are: (1) Establishment of the learning community, (2) Teacher demographics, (3) Teacher activity, (4) School demographics (5) Student demographics, (6) Student activity, (7) Student learning.

Telecomunicando

The Telecomunicando project is aimed at exploring the didactic use of technology. New hypermedia products and classroom activities are developed which are meant to be used as tools to support the construction processes in students. These technologies also include tools for computer-mediated communication. The project involves fifteen Italian schools (primary and high schools) which build a community where joint hypertext applications are constructed (Caravita, Pontecorvo & Talamo, 1996, Talamo & Pontecorvo, 1997).

Classes involved in the project work on the construction of hypermedia presentations of cultural objects and attractions located near to their schools. Children actively participate in the research and in the selection of materials as well as in the design of a hypertext structure and its computer implementation.

The full project is based on communication and cooperation at many levels. In order to facilitate a computer-mediated communication, schools have been supplied with technological supports: e-mail addresses, ISDN connection for videoconferencing and internet access.

Classes have also been involved in a reciprocal revision process: students of the same level can express their appraisal of work done by companions in other towns. Schools are supported by teams of experts that provide help in managing the introduction of technological resources, and in pedagogical decision making (like social organization of the children, introduction of project-oriented activities in the syllabus, analysis of processes that activate the social construction of knowledge). Vertical communication between teachers at different levels is also available during monthly meetings. Communication via e-mail between experts permits the activation of a discussion group on the pedagogical and technological implications of the project.

The Telecomunicando project made it possible to test new methods of communication and cooperation, enlarging opportunities for exchange inside and outside the classrooms. The activation of many communicative channels placed schools in a wide context which supported information management activities during the hypermedia implementation. This point emerges particularly from the analysis of all the levels of communication in which students have been involved inside the project. The first level of communication implies activities inside the classroom; the children’s discussion is stimulated by the project in all phases of work. This was possible because all the children work on a common product. The second level is represented by the communication with other schools of the same level, that is, *horizontal communication*, in order to exchange opinions and suggestions about work done. The third level was *vertical communication* in the network: some classes communicated with schools of other orders to ask for help when they felt they did not have the skills or competencies needed for the work they were doing. The first three levels of communication flow are still in a school context. The opportunity of working on the project consists of encouraging schools to make contacts with the outside world, to ask for information from experts of various fields. Their contribution implies a reference to real-life contexts. Thus the wider communication context is the link between learning at school and exploration of the real world and gives a cultural context to class activities.

Another important aspect concerns communication forms: the introduction of telematic technologies permitted experimentation with different specialized communication practices. The opportunity to use different communication systems illustrated the problem of the specificity of communication forms and codes in relation to the available instruments.

The project emphasizes the constructive nature of knowledge acquisition: children take part in a context in which constructive activity becomes a wide collective process. Collaboration inside and outside the classroom means redefinition of learning context as an environment wider than the class or the school in which students work. Direct exchange, implemented through technological supports, activates cooperation between the schools in revising each other's work. The network of linkages in which students are involved makes it possible to experiment with new forms of cooperation in which producers and users of hypermedia applications work together. Hypertexts are produced for an audience and the audience participates in the construction of the product. The interactive elaboration of the hypermedia application includes suggestions concerning the choice of content (what would be pleasant), expressive language (how to express something more fully) and the project of future work (how the work will continue). The reciprocal communication and the revision ties between schools help students to develop their *"metaconceptual awareness"* (Vosniadou, 1994) through public discussions of their representations.

It can be seen in the following example how, during the interaction via the videoconference, explicit reference to children's representations of what to include in the hypertexts (games, "culture") also emerges.

T. [Rome]:*Guys, let's try to understand what's wrong with the text about the square, let's clear up these points, and next time we'll be more careful!*

B. [Rome]: *We are looking at the square and trying to see what it was like before and then we'll make some tests, and how we'd like it to be, and then some games.*

T.[Genoa]: *<u>We've already taken your advice about putting in more games</u>, actually we're already studying them, so we'll make another hypertext in which there will be a large number of games.*

D. [Rome]: *Yes, I know, what's wrong with our hypertext*?

[...]

T. [Genoa]: *The hypertext is all right, but, as you said that in ours there weren't enough games, children in our class found that in yours there wasn't enough information, but this simply means that <u>there was too little cultural content</u>, but, for the rest, it is nice*.

The construction of a hypermedia aimed at describing cultural objects implies a great amount of research activity for the retrieval of information. Furthermore, the creation of an educational environment requiring exploration activities facilitates the concretization of the study object through the acquisition of knowledge related to direct experience. The work on the project also modified learning processes because it offered new opportunities for collective reasoning on learning objects. The work on a product, in front of an audience, that is, the realization of a product in a real communication context, stimulates the production of a well-done piece of work. Discussions between students on what is a good representation of learning content, activates metacognitive representation of knowledge and its organization: to construct a hypermedia, some communicative skills must be put into action (like the choice of the most effective communicative strategies).

The two are the most relevant dimensions involved in the project are cognitive skills and relational competence. The Telecomunicando project stimulates the complex organization of information, the identification of links between information units, the selection of relevant information skills and the choice of different communicative codes in relation to the communication content.

Studies on the results of the participation in the project (Talamo & Pontecorvo, in press; Talamo & Menotti, in press) confirm the evidence that Telecomunicando stimulates students' cognitive, metacognitive and social skills. Data has been collected on products and on working modalities. The comparison between experimental and control classes on a task of hypertext construction shows that students who work on the project:

?? Were more able in activities that require metacognitive skills;

?? Work preferably in collective ways rather than in individual modalities;

?? Construct products which imply a complex conceptual organization and a strong integration between information units.

The Telecomunicando project, as a productive learning environment in a real communication context, stimulates an increase in students' cognitive skills in the sharing of information and in the organization of the production process. Working on hypermedia construction in a network implies not only the discussion about information organization, but also the management of working procedures, which means that students discover and practice rules of social organization, and collaborate actively for the creation of a culture of collective reasoning.

CONCLUSIONS

Computer Supported Collaborative Learning is closely related to the recent development in theories of learning and instruction. For many researchers some kind of CSCL application seems to be one of the most promising ways of using information technology to put forward desired changes in educational practice. According to the literature reviewed above, there are two kinds of evidence supporting the educational value of CSCL. Firstly, it is obvious that introducing a computer environment can improve the amount and quality of social interaction among students and between teachers and students. This seems to be true even when computer applications originally planned for individual use have been implemented in a classroom context. When applications, in addition, provide students and teachers with special groupware functions (e.g. network connections, joint databases, interaction supporting interfaces) the facilitation of high quality social interaction is naturally more obvious. These tools make the sequence of interaction events more visible for participants which opens better possibilities for mutual understanding among the students and between the teacher and the students. Groupware also helps the participants to coordinate their activities towards the joint tasks (Järvelä et al, 1999). With the help of groupware technology it has been possible to create interaction processes in which students are consciously constructing new knowledge (solutions, theories, models) on an inter-subjective or social level.

Secondly, there is a reasonable amount of published experiments showing positive learning effects when CSCL systems have been applied in classroom learning. Most of the studies are, however, rather limited in terms of the duration of the experiment, the number of participants, and the share of the curriculum covered. In spite of these limitations, there are some important qualities in the results which make them noteworthy. Reported positive results indicate that improvement in student learning is found particularly in higher order cognitive processes and in the skills we could define as representing so-called information society skills. These are skills which are generally supposed to be crucial for people when coping with the demands and opportunities of the future work and other activities in the information society.

Although the scientific community has considered the principles of CSCL highly promising for the development of future learning environments, this is not yet the case among practising teachers. For example, in a recent large survey study, Finnish teachers did not regard collaborative learning as an important application of computers (Hakkarainen et al., 1998). This result is at least partly a consequence of the novelty of the CSCL ideas in schools, but it also indicates that the theoretical and practical principles of CSCL are still too immature to be widely applied in practical educational reforms. There is a need for theoretically well grounded development of CSCL environments and tools which are adequately embedded in a practical educational context. In an experimental situation, it is typical that enthusiastic teachers are working in a well-equipped environment in which they are maximally supported by the researchers and technical aids. In these conditions, it is possible to obtein positive results even if the technical tools and pedagogical arrangements are not generally adequate in relation to the constraints of school culture, curricular demands, teachers' competencies, students' motivation and learning orientation etc (see Järvelä, Lehtinen & Salonen, 1999; Lehtinen et al, 1997). In attempts to scale up the models of intensive pilot experiments we frequently face the problem that the technological skills and pedagogical beliefs of teachers are not appropriate in relation to the requirements of the new learning environment (see Hakkarainen et al., 1998).

In analysing the constraints of implementing CSCL methods in the school context we obviously face problems similar to those which have been reported in research on the impact of Computer Supported Collaborative Work. Groupware has proved to be a useful tool for enhancing collaboration in an organisation when certain presuppositions are fulfilled. The necessary conditions for successful implementation of groupware are that the organisation's members have a need to collaborate; they understand how the technology can support collaboration, and the organisational culture supports collaboration. If these presuppositions are not fulfilled in the organisation the implementation of a groupware-based system may be difficult or it leads to ostensible activities. In the school context, this means that a groupware application is not enough for changing the teaching-learning processes towards the desired CSCL, but simultaneous attempts to change the whole collaboration culture of the classroom (or the whole school) are also needed. More generally, it is important to notice that in applying theoretical ideas and experiences from other counties it is important to consider that there might be national or local cultural practices and beliefs that conflict with the intended teaching and learning methods (see Hakkarainen et al., 1996; Lehtinen et al. 1997). The future research on CSCL should more systematically focus on the cultural, organisational, and individual constraints of the school context and the teaching-learning situation.

Results of the research on CSCW also indicate that the features of the groupware used are important. There has been a reasonable body of papers aimed at systematically analysing which features of groupware can optimally facilitate effective collaborative work in different organisations. However, in the literature of CSCL there was no study systematically comparing the impact of different CSCL tools. A careful analysis of the differences between more and less successful applications could provide better guidelines for developing new tools for different pedagogical situations. In developing new tools for CSCL or in comparing the already existing ones several aspects should be considered. According to the experiences of CSCW, a crucial question is who benefits from a groupware system. Although the hierarchy and the division of labour is simpler in schools than it is in work organisations, it is obvious that also in the educational context a groupware application never provides precisely the same benefit to every group member, but individual costs and benefits depend on preferences, prior experience, roles, and assignments. As in a work context, also in an educational setting, groupware often requires that some people do additional work to enter or process information that the application requires or produces. If this is not experienced as a natural and useful part of the study or teaching process it is not likely that this tool will be accepted by all the participants and this correspondingly limits the usefulness of the application.

Central to the group activity are social, motivational, and emotional factors that are difficult to implement in computer applications. In human face-to-face communication, social, motivational, and emotional meanings are mediated by using different verbal and non-verbal communication acts. If the groupware is designed to replace these activities by mere computer-mediated communication it can even decrease the effectiveness of communication because of the limited repertoire of modalities. One of the main challenges for the development of groupware and other technologies for collaborative learning is to create tools which can meet the motivational demands and particularly support the sharing of informal and tacit knowledge.

An additional lesson we can learn from the results of CSCW research is that groupware often requires that users carry out activities that do not naturally belong to their work, or else the tools support activities which are infrequent in normal work and do not help users to carry out their most frequent activities. This problem we can probably also face in the educational context. Some of the activities we expect students or teachers to perform in the CSCL environment can be considered artificial or insignificant by them and thus difficult to apply as a natural part of the study process.

The development of network technology and software is very rapid. This development opens up new opportunities to create powerful CSCL environments. The multimedia elements added to network applications make them very attractive. It is not, however, self-evident whether these new tools also have pedagogical value without carefully planned instructional strategies and adequately trained teachers. It is obvious that CSCL applications will be one of the dominating branches of educational technology in near future. However, many problems have to be solved before CSCL is generally used in normal classroom

REFERENCES

Ahern, T.C., Peck, K. & Laycock, M. (1992). The effects of teacher discourse in computer mediated discussion. Journal of Educational Computing Research 8 (3), 291-309.

Alavi, M. (1994) Computer-mediated Collaborative Learning: An Empirical Evaluation. MIS Quartely, Vol. 18, Issue 2, p.159.

Amigues, R. & Agostinelli, S. (1992) Collaborative problem-solving with computer: How can an interactive learning environment be designed? European Journal of Psychology of Education, Vol. VII, no. 4, 325-337.

Anderson, J. R. (1990) The adaptive character of thought. Hillsdale, NJ.: Lawrence Erlbaum.

Anderson, A., Mayes, T. J. & Kibby, M. R. (1995) Small Group Collaborative Discovery Learning from Hypertext. In C. O´Malley (Ed.) Computer Supported Collaborative Learning. NATO ASI Series F: Computer and systems sciences, vol 129. Heidelberg Berlin: Springer-Verlag 23-38.

Aronson, E., Blaney, N., Srephan, C., SikesJ., & Snapp, M. (1978) The Jigsaw classroom. Beverly Hill: CA: Sage.

Baker, C. (1985) The microcomputer and the curriculum. A critique. Journal of Curriculum Studies, 17, 449-451.

Barker, & Kemp, 1990. "Network Theory: A Postmodern Pedagogy for the writing classroom in Handa,C.(ed.) Computers and Community:Teaching Composition in the twenty-first century. Boynton/Cook, Portsmouth, New Hampshire.

Baker, M., Levy Cohen, J. & Moeller, B. (1997) KidCode: Using Email to structure interactions for elementary mathematics instruction. In R. Hall, N. Miyake & N. Enyedy (Ed.) Computer Support for Collaborative Learning ´97. Proceedings of The Second International Conference on Computer Support for Collaborative Learning. December 10-14, 1997. Toronto, Ontario, Canada, 1-9.

Baker, M. & Bielaczyc, K. (199). Missed opportunities for learning in collaborative problem-solving interactions.

Baskerville, R., Smithson, S., Ojelanki, N. & Degross, J. 1995. Information technology and new organizational forms: Choosing chaos over panaceas. European journal of information systems 4 (2), 66-73.

Bates, A. W. 1995. Technology, Open Learning and Distance Education. London Routledge.

Bell, P. (1997) Using argument representations to make thinking visible for individuals and groups. In R. Hall, N. Miyake & N. Enyedy (Ed.) Computer Support for Collaborative Learning ´97. Proceedings of The Second International Conference on Computer Support for Collaborative Learning. December 10-14, 1997. Toronto, Ontario, Canada, 10-19.

Bereiteter, C. (1994) Constructivism, socioculturalism, and Popper’s world 3. Educational

Researcher 23 (79), 21-23.

Bereiter, C. & Scardamalia, M. (1989) Intentional learning as a goal of instruction. In L. B. Resnick (Ed.) Knowing, learning, and instruction: Essays in honor of Robert Glaser. (pp. 361-392). Hillsdale, NJ: Lawrence Erlbaum.

Bereiter, C. & Scardamalia, M. (1991a) Models of educational use of a communal database. Paper to be presented at the NATO Advanced Research Workshop, "Advanced Educational Technology: Instructional Models in Computer-Based Learning Environments", University of Twente, The Netherlands.

Bereiter, C., & Scardamalia, M. (1991b) First, second- and third-order approaches to fostering cognitive strategies in writing. Paper presented at the conference on Intervention in Education, Madrid, Spain

Bereiter, C. & Scardamalia, M. (1993) Surpassing ourselves: an inquiry into the nature and implications of expertise. Chicago and La Salle, IL: Open Court.

Bielaczyz, K., Brown, A. N., & Pirolli, P. (1994) Collaborative explanations and metacognitions: Indentifying successful learning activities in acquisition of cognitive skills. Paper presented at the Annual Meeting of the American Educational Research Association, New Orleans, April 1994.

Blaye, a. & Light, P. (1995) Collaborative Problem Solving with HyperCard: The Influence of Peer Interaction on Planning and Information Handling Strategies. In C. O´Malley (Ed.) Computer Supported Collaborative Learning. NATO ASI Series F: Computer anf systems sciences, vol 129. Heidelberg Berlin: Springer-Verlag, 3-22.

Bonk, C. J. & King, K. S. (1995). Computer Conferencing and Collaborative Writing Tools: Starting a Dialogue About Student Dialogue. Proceedings of the CSCL ’95 Conference.

Brown, A. & Campione, J. (1994) Guided discovery in a community of learners. In K. McGilly (Ed.), Classroom lessons: Integrating cognitive theory and classroom practice (pp. 229-270). Cambridge, MA: Bradford Books, MIT Press.

Brown, A. L. & Campione, J. C. (1996) Psychological theory and the design of innovative learning environments: On procedures, principles, and systems. In L. Schauble. & R. Glaser (Eds.) Innovations in learning. New environments for education. (pp. 289-325). Mahwah, NJ: Lawrence Erlbaum.

Brown, A. L., & Palincsar, A. S. (1989) Guided, cooperative learning and individual knowledge acquisition. In L. Resnick (Ed.), Knowing, learning, and instruction: Essays in Honor of Robert Glaser. (pp. 393-451) Hillsdale, NJ: Lawrence Erlbaum.

Bruckman, A. & De Bonte, A. (1997) MOOSE goes to school: A comparison of three classrooms using a CSCL environment. In R. Hall, N. Miyake & N. Enyedy (Ed.) Computer Support for Collaborative Learning ´97. Proceedings of The Second International Conference on Computer Support for Collaborative Learning. December 10-14, 1997. Toronto, Ontario, Canada, 20-26.

Brush, T. A. (1997) The effects on student achievement and attitudes when using integrated learning systems with cooperative pairs. Educational Technology Research & Development 45 (1), 51-64.

Bump, J. 1990 Radical changes in class discussion using networked computers. Computers and the Humanities 24 (1-29, 49-63.

Butler, W. M. (1995) Writing to Learn History On-line. Clearning House, Vol. 69, Issue 1, p.17.

Butler, W.M. & Kinneavy, J.L. (1991) The Electronic Discourse Community: god, Meet Donald Duck.". In The writing Teacher's Sourcebook Ed. Tate, G., Corbett, E. P. J. & Meyers, N. 3 rd ed.. New York: Oxford UP,1994, 400-14.

Caravita, S., Pontecorvo, C., Talamo, A.,(1996) *Exchange of cultural goods among schools*, Poster presented at the congress "The Growing Mind", Geneve, 15-18 september 1996.

Carey, S. & Smith, C. (1995) On understanding scientific knowledge. In D. N. Perkins, J. L. Schwartz, M. M. West, & M. S. Wiske. (Eds.) Software goes to school. (pp. 39-55). Oxford: Oxford University Press.

Carrier, C.A. & Sales, G.C. (1987). Pairs versus individual work on the acquisition of concepts in a computer-based instruction lesson. Journal of Computer-Based Instruction, 14, 11-17.

Chan, C., Burtis, J., & Bereiter, C. (1997) Knowledge building as a mediator of conflict in conceptual change. Cognition and Instruction, 15, 1-40.

Cherniak, C. (1986) Minimal rationality. Cambridge, MA: The MIT Press.

Chyung, S-Y., Repman, J., & Lan, W. (1995). Academic Risk-Taking and CSCL . Proceedings of The Second International Conference on Computer Support for Collaborative Learning.

Cohen, A. (1994) The effect of individual work on collaborative student activity in a CSILE classroom. Paper presented at the symposium titled "Computer Supported Collaboration for Scientific Inquiry: Bringing Science Learning Closer to Scientific Practice", Annual meeting of American Educational Research Association, New Orleans, April 1994.

Coleman, D. (Ed.) (1997). Groupware: Collaborative Strategies for Corporate LANs and Intranets. Prentice Hall.

Collins, A., Brown, J.S. & Holum, A. (1991). Cognitive Apprenticeship: Making Thinking Visible. American Educator, 6-11, 38-46.

Collins, A. & Brown, J.S. (1988). Computer as a tool for learning through reflection. In: H. Mandl & A. Lesgold (Eds.), *Learning issues for intelligent tutoring systems*. (pp.1-18) New York: Springer-Verlag

Crook, C. (1994) Computers and the collaborative experience of learning. London:

Routledge.

Cuban, L. (1986) Teachers and machines. New York: Teachers College Press.

Dalton, D.W., Hannfin, J. & Hooper, S. (1987). Effects of individual and cooperative computer-assisted instruction on student performance and attitudes. Educational Technology, Research and Development, 37 (2), 15-24.

Damon, W. 1984. Die soziale welt des kindes. Frankfurt an Main: Suhrkamp.

Damon, W. & Phelps, E. (1989) Critical distinctions among three approaches to peer education. International Journal of Educational research, 13 (1), pp. 9-19.

Davenport, T. (1996). Think tank: software as socialware. CIO,1, 24--26.

Davis, J. R. & Huttenlocher, D.P (1995). Shared Annotation for Cooperative Learning. Proceedings of CSCL'95:The First International Conference on Computer Support for Collaborative Learning. Mahwah, NJ, USA: Lawrence Erlbaum Associates, Inc.

De Corte, E. (1993) Psychological aspects of changes in learning supported by informatics. In D. C. Johnson & B. Samways. (Eds.). Informatics and changes in learning. (A-34). Proceedings of the IFIP TC3.1/WG3.5 Open Conference on Informatics and Changes in Learning. Gmunden, Austria 7-11 June, 1993. Amsterdam: North-Holland.

Dede, C. (1996) Emerging Technologies in Distance Education for Business. Journal of Education for Business, Mar/Apr96, vol. 71, issue 4, 197-204.

Delaney, C. F. (1993) Science, knowledge, and mind. A study in the philosophy of C. S. Peirce. Notre Dame: University of Notre Dame Press.

Derry, S. J. 1990. Remediating academic difficulties through strategy Training: The acquisition of useful knowledge. Remedial and special education RASE 11 (8), 19-31.

Devin-Sheehan, L., Feldman, R., & Allen, V. (1976) Research on children tutoring children: A critical review. Review of Educational Research, 46 (39), 355-385.

Dillenbourg, P., Baker, M, Blaye, A & O'Malley, C (1996) The evolution of Research on Collaborative Learning In H. Spada and P. Reimann (Eds) Learning in Humans and Machines. Elsevier.

Dillenbourg, P., Mendelsohn, P. & Schneider, D. (1994) The distribution of pedagogical roles in a multi-agent learning environment. In R. Lewis & P. Mendelsohn (Eds.) Lessons from Learning (p. 199-216). Amsterdam: North-Holland

Dillenbourg, P. & Self, J. A. (1992) A computational approach to socially distributed cognition. European Journal of Psychology of Education, Vol. 7, No. 4, 352-373.

Dillenbourg, P. & Baker, M. (1996) Negotiation Spaces in Human-Computer Collaborative Learning. Proceedings of COOP´96, Juan-les-Pins, France, June.

Doise, W. & Mugny, W. 1984 The Social Development of the Intellect. Oxford: Pergamon

Press.

Dunbar, K. (1995) How scientists really reason: Scientific reasoning in real-world laboratories. R. J. Sternberg. & J. Davidson. (Eds.) Mechanisms of insight. (pp. 365-395). Cambridge, MA: MIT Press.

Edelson, D.C. (in press). Realising authentic science learning through the adaptation of scientific practice. In K. Tobin & B. Fraser (Eds.), International handbook of science education. Dordrect, NL: Kluwer.

Edelson, D., Pea, R., & Gomez, L. (1996). Constructivism in the Collaboratory. In B. G. Wilson (Ed.), Constructivist learning environments: Case studies in instructional design, (pp. 151-164). Englewood Cliffs, NJ: Educational Technology Publications.

Edelson, D.C., & O'Neill, D.K. (1994). The CoVis Collaboratory Notebook: Supporting collaborative scientific inquiry. In A. Best (Ed.), Proceedings of the 1994 National Educational Computing Conference (pp.146-152). Eugene, OR: International Society for Technology in Education in cooperation with the National Education Computing Association.

Enyedy, N., Vahey, P. & Gifford, B. R. (1997) Active and supportive computer-mediated resources for student to student conversations. In R. Hall, N. Miyake & N. Enyedy (Ed.) Computer Support for Collaborative Learning ´97. Proceedings of The Second International Conference on Computer Support for Collaborative Learning. December 10-14, 1997. Toronto, Ontario, Canada, 27-36.

Eraut, M. (1995) Groupwork with computers in British primary schools. Journal of Educational Computing Research 13(1), 61-87.

Faigley, L.(1992) Fragments of Rationality: Postmodernity and the Subject of Composition. U of Pittsburgh P.

Fishman, B. J. & Gomez, L. M. (1997) How activities foster CMC tool use in classrooms. In R. Hall, N. Miyake & N. Enyedy (Ed.) Computer Support for Collaborative Learning ´97. Proceedings of The Second International Conference on Computer Support for Collaborative Learning. December 10-14, 1997. Toronto, Ontario, Canada, 37-44.

Fetcher-Flinn, C. M. & Gravatt, B. 1995. The Efficacy of Computer Assisted Instruction (CAI): A meta-analysis. Journal of Educational Computing research 12 (3), 219-41.

Forman, E. A. & Cazden, C. B. 1985. Exploring vygotskian perspectives in education: the cognitive value of peer interaction. In Culture, Communication and Cognition: Vygotskian Perspectives, J. V. Wertsch ed., Cambridge U.K., Cambridge University Press.

Frederiksen, J. R. & White, B. Y. (1997). Cognitive facilitation: A method for promoting reflective collaboration. In R. Hall, N. Miyake & N. Enyedy (Ed.) Computer Support for Collaborative Learning ´97. Proceedings of The Second International Conference on Computer Support for Collaborative Learning. December 10-14, 1997. Toronto, Ontario, Canada, 53-62.

Friedman, L.B. & McCullough, J. (1992). Computer conferencing as a support mechanism for teacher-researchers in rural high schools. Teoksessa M.D. Waggoner (Toim.) Empowering networks. Computer conferencing in education (pp. 139 - 155). Educational Technology Publications. New Jersey.

Goldberg, M. and Salari, S. (1997). An Update on WebCT (World-Wide-Web Course Tools) - a Tool for the Creation of Sophisticated Web-Based Learning Environments", Proceedings of NAUWeb '97 - Current Practices in Web-Based Course Development, June 12 - 15, 1997, Flagstaff, Arizona.

Gomez, L., Gordin, D., Carlson, P. (1995). A case study of open-ended scientific inquiry in a technology supported classroom. In J. Greer (Ed.) Proceedings of AI-Ed '95, Seventh World Conference on Artificial Intelligence in Education (pp. 17-24). Charlottesville, VA: Association for the Advancement of Computing in Education.

Graves, D. (1983). Writing: Teachers and children at work. Exeter, NH: Heinemann.

Graves, D. & Klawe, M. (1997) Supporting learners in a remote CSCL environment: The importance of task and communication. In R. Hall, N. Miyake & N. Enyedy (Ed.) Computer Support for Collaborative Learning ´97. Proceedings of The Second International Conference on Computer Support for Collaborative Learning. December 10-14, 1997. Toronto, Ontario, Canada, 63-72.

Grudin, J. (1991). Obstacles to user involvement in software product development, with implications for CSCW. *International Journal of Man-Machine Studies, 34,* 3, 435-452.

Hakkarainen, K. (1998, April). Cognitive value of peer interaction in computer-supported collaborative learning environment. Paper to be presented at the Annual Meeting of the American Educational Research Association, San Diego.

Hakkarainen, K. & Lipponen, L. (1998, April). Epistemology of inquiry and computer-supported collaborative learning. Paper to be presented at the Annual Meeting of the American Educational Research Association, San Diego.

Harasim, L. (1997, May). Interacting in hyperspace: Developing collaborative learning environments on the WWW. Paper presented at the Workshop on Improving Economic Management Training, Marocco.

Harasim, Linda. (1994). Computer Networking for Education. In T. Husen, and T.N. Postlethwaite, (Eds.). The International Encyclopedia of Education, 2nd Edition. Oxford, U.K: Pergamon Press.

Harasim, L., Hiltz, R., Teles, L., and Turoff, M. (1995) Learning Networks: A Field Guide to Teaching & Learning Online. Cambridge, MA: MIT Press.

Harman, G. (1986) Change in view. Cambridge, MA: The MIT Press.

Hatano, G. & Inakagi, K. 1987. Young children’s spontaneous personification as analogy. Child Development 58 (4), 1013-20.

Hatano, G. & Inagaki, K. (1991) Sharing cognition through collective comprehension activity. In L. B. Resnick, J. M. Levine & S. D. Teasley (Eds.) Perspectives on socially shared cognition. (pp. 331-348). Washington DC: American Psychological Association.

Hatano, G. & Inagaki, K. (1992) Desituating cognition through the construction of conceptual knowledge. In P. Light & G. Butterworth (Eds.) Context and cognition. Ways of knowing and learning. (pp. 115-133). New York: Harvester.

Hatano, G. & Inagaki, K. (1995) Young children's naive theory of biology. In J. Mehler & S. Frank (Eds.). Cognition on cognition. (pp. 153-170). Cambridge, MA: The MIT Press.

Hawisher, G.-E. & Selfe, C-L. (1991) The Rhetoric of Technology and the Electronic Writing Class. College-Composition and Communication 42 (1), 55-65.

Hiltz, S.R., and Turoff, M. (1993). The Network Nation: Human Communication via Compute***r***. Cambridge, MA: MIT Press.

Hmelo,C.E., Vanegas, J.A., Realff, M., Bras, B, Mulholland, J , Shikano, T., & Guzdial, M. (1995). Technology Support for Collaborative Learning in a Problem-Based Curriculum for Sustainable Technology. Proceedings of The Second International Conference on Computer Support for Collaborative Learning.

Hooper, S. & Temiyakarn, C. 1993. The effects of cooperative learning and learner control on high and low achievers. In Proceedings of Selected research and Development Presentations at the convention of the Association for Educational communications and technology.

Howell-Richardson, C & Mellar, H. (1993). The effect of CMC course design on patterns of participation. Paper presented at the 5th European Conference for Research on Learning and Instruction, August 31 - September 4. Aix-en-Provence, France.

Hativa, N. (1988). Computer-based drill and practice in arithmetic. Widening the gap between high - and low-achieving students. American Educational Research Journal, 25, 366-397.

Hawkins, J., Sheingold, K., Gearhart, M. & Berger, C. (1982) Microcomputers in schools: Impact on the social life of elementary classrooms. Journal of Applied Developmental Psychology, 3, 361-373.

Hewson, P. W. & Hewson, M. A. 1984. The role of conceptual conflict in conceptual change and the design of science instruction. Instructional Science, 13 (1), 1-13.

Holyoak, K. J. (1991) Symbolic connectionism: toward third-generation theories of expertise. In K. A. Ericsson & J. Smith, J. (Eds.), Toward a general theory of expertise. Prospects and limits. (pp. 301-335). Cambridge: Cambridge University Press.

Hooper, S. (1992). The effects of peer instruction on learning during computer-based mathematics instruction. Journal of Educational Research, 85, 180-189.

Hooper, S & Hannfin, M.J. (1988). Cooperative CBI: The effects of heterogeneous versus homogeneous grouping on the learning of progressively complex concepts. Journal of Educational Computing Research, 4, 413-424.

Hoyles, C. & Shutterland, R. (1989). Logo mathematics in the classroom. London: Routledge.

Hoyles, C., Healy, L. & Schutterland, R. (1991). Patterns of discussion between pupil pairs in computer and non-computer environments. Journal of Computer-Assisted Learning, 7, 210-226.

Hutchins, E. (1991) The social organization of distributed cognition. In L. B. Resnick, J. M. Levine & S. D. Teasley (Eds.). Perspectives on socially shared cognition. (pp. 283-307). Washington, DC.: American Psychological Association.

Hutchins, E. (1995) Cognition in the wild. Cambridge, MA: The MIT Press.

Isenberg, R. (1992). Social skills at the computer. Our Link, Cooperative Learning Newsletter, 2 (6) 1-2.

Johnson, D.W., & Johnson, R.T. (1992). Positive interdependence: Key to effective cooperation. In R. Hertz_Lazarowitz & N Miller (Eds.). Interacting in cooperative groups. The theoretical anatomy of group learning (pp. 145-173). New York: Cambridge University Press.

Johnson, D.W.,& Johnson, R.T. (1994). Learning together and alone: Cooperative, competitive, and individualistic learning. Boston MA: Allyn & Bacon.

Johnson, R.T., Johnson, D.W., & Stanne, M. (1985). Comparison of computer-assisted cooperative, competitive, and individualistic learning. American Educational Research Journal, 23, 382-392.

Järvelä, S. (1996). New models of teacher-student interaction: A critical review. European Journal of Psychology of Education. 6 (3), 246-268.

Järvelä, S., Bonk, C.J., Lehtinen, E. & Hämäläinen, S. 1998. Turning towards Joint Task: Goal-oriented teacher-student interaction and reciprocal understanding in technology-based learning enviroments. Submitted.

Järvelä, S. & Lehtinen, E., & Salonen, P. (1998). Socioemotional orientation as a mediating variable in teaching learning interaction: Implications for instructional design (forthcoming).

Kato, H. & Ide, A.(1995) Using a Game for Social Setting in a learning Enviroment: Algoarena – A Tool for Learning Software Design. Information Technology Research Laboratories, NEC Corporation.

Katz, S. & Lesgold, A. 1993. Collaborative Problem-Solving and Reflection in Sherlock II. In Proceeding of the Workshop on collaborative Problem Solving: Theoretical frameworks and Innovative systems, Edinburgh.

Khalili, A. & Shashaani, L. (1994) The Effectivness of Computer Applications: A Meta-analysis. Journal of Research on Computing in Education 27 (1), 48-62.

Kiely, T. (1993). Learning to share. CIO, 6, 15, 38--44.

Kitcher, P. (1989) Explanatory unification and the causal structure of the world. In P. Kicher & W. Salmon (Eds.) Scientific explanation. Minnesota Studies in the philosophy of science XIII. (pp. 410-505). Minneapolis: University of Minnesota Press.

Kitcher, P. (1990) The division of cognitive labor. The Journal of Philosophy, 87, 5-22.

Kitcher, P. (1993) The advancement of science. New York: Oxford University Press.

Kreuger, L.W., Karger, H., and Barwick, K. (1989). A critical look at children and micro-computers: Some phenomenological observations. In J.T. Pardeck and J.W. Murphy (Eds.). Microcomputers in early childhood education. New York: Gordon & Breach.

Kulik, J.A. & Kulik, C.-L.C. (1987). Review of recent research literature on computer-based instruction. Contemporary Educational Psychology, 12 (3) 222-230.

Kulik, C. & Kulik, J. 1991. The effectivness of computer-based Instruction: An updated analysis.

Kulik, C. & Kulik, J. 1994. Meta-analytic studies of findings on computer-based instruction. In Baker, E. L. and O'Neill, H. F. (Eds.) technology Assessment in Education and Training. Hillsdale, NJ: Lea Publishers.

Kupperman, J.; Wallace, R. & Bos, N. (1997) Ninth graders´use of a shared database in an Internet research project: Issues of collaboration and knowledge building.In R. Hall, N. Miyake & N. Enyedy (Ed.) Computer Support for Collaborative Learning ´97. Proceedings of The Second International Conference on Computer Support for Collaborative Learning. December 10-14, 1997. Toronto, Ontario, Canada, 157-163.

Lamon, M. (1992) Learning environments and macro-contexts: Using multimedia for understanding mathematics. Paper presented at the annual meeting of the American Educational Research Association, San Francisco, April.

Lamon, M., Secules, T., Petrosino, A., Bransford, J., & Goldman, S. (1996) Schools for thought: overview of the project and lessons learned from one of the sites. In L. Schauble & R. Glaser (Eds.) Innovations in learning. New environments for education. (pp. 243-288). Mahwah, NJ: Erlbaum.

Latour, B. & Woolgar, S. (1986/1979). Laboratory life. The construction of scientific facts. Princeton, NJ: Princeton University Press.

Latour, B. (1988). Drawing things together. In Lynch, M. & Woolgar, S. (eds.) Representation in scientific practice. (pp. 19 - 68) Cambridge, MA: The MIT Press.

Lea, M. (Ed.)(1992). Contexts of computer-mediated communication. London: Harvester-Wheatsheaf.

Lehtinen, E. (1984). Motivating students towards planning and controlling of thinking activities: A constructivist approach to learning. Annales Universitatis Turkuensis, Ser. B, 164.

Lehtinen, E. & Repo, S. (1996). Activity, social interaction and reflective abstraction: Learning advanced mathematics in a computer environment. In S. Vosniadou, E. De Corte, R. Glaser & H. Mandl (Eds.), International perspectives on the design of technology supported learning environments (105-128). Mahwah, NJ: Lawrence Erlbaum.

Lehtinen, E. & Rui, E. (1996). Computer supported complex learning: An environment for learning experimental method and statistical inference. Machine Mediated Learning 5 (3&4), 149-175.

Lehtinen, E., Hämäläinen, S. & Mälkönen, E. (1998). Learning experimental research methodology and statistical inference in a computer environment. A paper presented at the American Educational Research Association (AERA) Annual Meeting, San Diego, April 13 to 17, 1998.

Lehtinen, E., Hakkarainen, K., Järvelä, S., Lipponen, L. , & Ilomäki. L. (1997) Culture of inquiry in computer-supported learning. A poster presented at The 7th Conference for Research on Learning and instruction, Athens, Greece, August 26 to 30, 1997.

Lesgold, A. Weiner, A., & Suthers, D. (1995, August). Tools for thinking about complex issues. Paper presented at the 6th European Conference for Research on Learning and Instruction, Nijmegen.

Littleton, K., Light, P., Joiner, R. & Barnes, P. 1992. Pairing and gender Effects on Children´s Computer-Based Learning. European Journal of Psychology of Education, 7, 4, 311-324.

Malikowski, S.(1998) WEB-based Conferencing for Education. The Center for Excellence in Education.

Marshall, E.M. (1995). The collaborative workplace. Management Review (June), 24, 13-17.

Marttunen, M. (1994). Assessing argumentation skills among Finnish university students. Learning and Instruction 4 (2), 175-191.

Marttunen, M. (In press) Teaching argumentation skills in an electronic mail environment. Innovations in Education and Training International.

Marttunen, M. (In press) Electronic mail as a pedagogical delivery system: an analysis of the learning of argumentation. Research in Higher Education.

McConnell, D. 1994. Managing open learning in computer supported collaborative learning environments. Studies in higher education 19(3), 341-358.

McGee, S., & Pea, R. D. (1994). Cyclone in the classroom: Bringing the atmospheric sciences community into the high school. In Proceedings of the Third American Meteorological Society Symposium on Education, 74th Annual Meeting of the AMS (pp. 23-26), Nashville TN: American Meteorological Society.

Mead, G. H. (1977) On social psychology. Selected papers. Edited by A. Strauss. Chicago: The University of Chicago Press.

Mevarech, Z.R., Silber, O., & Fine, D. (1991). Learning with computers in small groups: Cognitive and affective outcomes. Journal of Educational Computing Research, 7, 233-243.

Miller, M.L. & Castellanos, J. (1996). Use of technology for science and mathematics collaborative learning. Schools Science and Mathematics, Vol 96, issue 2, 58-62.

Misak, C. J. (1990) Truth and the end of inquiry. A Peircean Account of Truth. Oxford: Clarendon Press.

Miyake, N. (1986). Constructive interaction and the iterative process of understanding. Cognitive Science, 10, 151-177.

M.P.I., STET, *Telecomunicando*. Atti del seminario di verifica del primo anno di sperimentazione. Roma, 11-12 settembre 1995.

Mugny, G. & Doise, W. (1978). Socio-cognitive conflict and structure of individual and collective performances. European Journal of Social Psychology, 8, 181-192.

Murray, F. B. (1983) Equilibration as cognitive conflict. Developmental Review, 3, 54-61.

Goldberg, M. and Salari, S. (1997). An Update on WebCT (World-Wide-Web Course Tools) - a Tool for the Creation of Sophisticated Web-Based Learning Environments", Proceedings of NAUWeb '97 - Current Practices in Web-Based Course Development, June 12 - 15, 1997, Flagstaff, Arizona.

Newman, D.R., Johnson, C., Cochrane, C. & Webb, B. (1996). An experiment in group learning technology: evaluating critical thinking in face-to-face and computer supported seminars. Interpersonal Computing and Technology 4 (1), 57-74.

Norman, D. A. (1993) Things that make us smart. Defending human attributes in the age of the machine. New York: Addison-Wesley.

Nurmela, K. & Lehtinen, E. (1998) WorkMates 3: User manual. In preparation. The Unit of Educational Technology, University of Turku.

Newman, D. R., Johnson, C., Webb, B. & Cochrane, C. (1997) Evaluating the Quality of Learning in Computer Supported Co-operative Learning. Journal of the American Society for Information Science, 48 (6), 484-495.

Oatley, K. (1991) Distributed cognition. In H. Eysenck, A. Ellis, E. Hunt, & P. Johnson-Laird (eds.) The Blackwell dictionary of cognitive psychology. (pp. 102-107). Oxford: Blackwell Reference.

O'Neill, D. K., Edelson, D. C., Comez, L. M. & D'Amigo, L.(1995) A design for Effective Support of Inquiry and Collaboration. Proceedings of CSCL'95:The First International Conference on Computer Support for Collaborative Learning. Mahwah, NJ, USA: Lawrence Erlbaum Associates, Inc.

Orlikowski, W. 1(992). Learning from NOTES: organizational issues in groupware implementation. Proceedings of the ACM Conference on Computer-Supported Cooperative Work. Toronto: October 31-November 4, 92 , pp. 362-369.

Palincsar, A.S. & Brown, A.L. (1984) Reciprocal Teaching of comprehension fostering and comprehension monitoring activities. Cognition and Instruction, 1 (2), 117-175.

Pea, R. D. (1993) Practices of distributed intelligence and designs for education. In G. Salomon (Ed.) Distributed cognitions. Psychological and educational considerations. (pp. 47-87). Cambridge: Cambridge University Press.

Pea, R.D. (1994). Seeing what we build together: Distributed multimedia learning environments for transformative communications. Journal of the Learning Sciences, 3(3), 283-298.

Pea, R.D., Edelson, E. & Gomez, L. (1994, April) The CoVis Collaboratory: High school science learning supported by a broadband educational network with scientific visualization, videoconferencing, and collaborative computing. Paper presented at the Annual Meeting of the American Educational Research Association, New Orleans.

Pea, R.D., Edelson, E. & Gomez, L. (1994, February). Distributed collaborative science learning using scientific visualization and wideband telecommunications. Paper presented at the 160th Meeting of the American Association for the Advancement of Science.

Phelps, R. H. et al. (1991) Effectiveness and Costs of Distance Education. Using Computer-mediated Communication. American journal of Distance Education 5 (3), 7-19.

Peirce, C. S. (1955) Philosophical writings of Peirce. Edited by Buchler, J. New York: Dover Publications.

Peirce, S. C. (1957) Charles S. Peirce. Essays in the philosophy of science. Edited by V. Tomas New York: The Liberal Arts Press.

Perkins, D. N. (1993) Person-plus: a distributed view of thinking and learning. In G. Salomon (Ed.) Distributed cognitions. Psychological and educational considerations. (pp. 88-110). Cambridge: Cambridge University Press.

Perkins, D. N. & Simmons, R. (1988) Patterns of misunderstanding: An integrative model for science, math and programming. Review of Educational Research, 58, 303-326.

Piaget, J. (1926). The Child's Conception of the World. Paris:Alcan.

Piaget, J. (1980). The Constructivist approach. Geneva: Foundation Archives Jean Piaget.

Pontecorvo, C. & Paoletti, G.(1989) Computer, Scrittura ed abilita metalinguistiche (Computers, writing and metalinguistic Abilities). Rassegna-Italiana-di-Linguistica-Applicata; 21 (1-2), 29-52.

Pontercorvo, C. (1986) 1. EARLI KIRJA

Puntambekar, S., Nagel, K., Hubscher, R., Guzdial, M. & Kolodner, J. L. (1997) Intra-group and intergroup: An exploration of learning with complementary collaboration tools.

Repman, J. (1993) Collaborative, computer-based learning: Cognitive and affective outcomes. Journal of Educational Computing Research 9(2),149-63.

Rescher, N. (1978) Peirce's philosophy of science. Critical studies in his theory of induction and scientific method. Notre Dame: University of Notre Dame Press.

Resnick, L. B., Pontecorvo, C., Saljo, R. & Burge, B. (1997) Discourse, Tools, and Reasoning, Berlin, Springer Verlag.Resnick, L. B. 1991. Perspectives on socially shared cognition. Washington D. C. :American psychological association.

Reusser, K. (1996). From cognitive Modelling to the Design of pedagogical tools. In Vosniadou, S. & De Corte, E. International perspectives on the design of Technology-Supported learning Enviroments, 81-103. Mahwah, NJ, USA: Lawrence Erlbaum Associates.

Rheingold, H. (1993) The Virtual community: Homesteading on the Electronic Frontier. Addison-Wesley, New York.

Riedl, R. (1989). Patterns in computer-mediated discussions. Teoksessa R. Mason & A. Kaye (Toim.) Mindweave. Communication, Computers and Distance Education (pp. 215 - 221). Oxford: Pergamon.

Roschelle, J. & Teasley, S. (in press) The construction of shared knowledge in collaborative problem solving. In C.E. O'Malley (Ed) Computer- supported collaborative learning. Heidelberg: Springer-Verlag

Roschelle, J. (1992) Learning by collaborating: Convergent conceptual change. Journal of Learning Sciences, 2, 235-276.

Ruberg, L.F., Moore, D.M & Taylor, C.D. (1996). Student participation, interaction, and regulation in a computer-mediated communication environment: a qualitative study. Journal of Educational Computing Research 14 (3), 243-268.

Rysavy, S.D.M. & Sales, G.C. (1991). Cooperative learning in computer based instruction. Educational Technology, Research & Development, 39 (2) 70-79.

Salomon, G. (1993) No distribution without individual's cognition: A dynamic interaction view. In G. Salomon (Ed.) Distributed cognitions. Psychological and educational considerations. (pp. 111-138). Cambridge: Cambridge University Press.

Salomon, G. (1996) Studying novel learning environments as patterns of change. In S. Vosniadou, E. De Corte, R. Glaser, & H. Mandl (Eds.) International perspectives on the psychological foundations of technology-based learning environments. (pp. 363-377). Mahwah, NJ: Lawrence Erlbaum.

Salomon, G. (in press a) Technology’s promises and dangers in a psychological context: implications for teaching and teacher education. Practice to Theory.

Salomon, G. (in press b) Unorthodox thoughts on the nature and mission of contemporary educational psychology. Review of Educational Psychology.

Salomon. G. (1994). Differences in patterns: Studying computer enhanced learning environments. In S. Vosniadou, E. De Corte & H. Mandl (Eds.), Technology-based learning environments: Psychological and educational foundations (pp. 79-85). NATO ASI Series F: Computer and System Science, Vol. 137. Berlin: Springer.

Salomon, G., Perkins, D. N., & Globerson, T. (1991) Partners in cognition: Extending human intelligence with intelligent technologies. Educational Researcher, April, 1991, 2-9.

Scardamalia, M., & Bereiter, C. (1989) Schools as knowledge-building communities. Paper presented at the Workshop on Development and Learning Environments, University of Tel Aviv, Tel Aviv, Israel, October, 1989.

Scardamalia, M. , Bereiter, C., McLean, R. S. & Swallow, J. & Woodruff. 1989. Computer-supported Intentional Learning Enviroments. Journal of Educational Computing research 5 (1), 51-68.

Scardamalia, M. & Bereiter, C. (1990) A Knowledge-building architecture for computer-supported learning. Paper presented at the NATO Advanced Research Workshop, "Computer-Based Learning Environments and Problem Solving", Leuven, Belgium, September, 1990.

Scardamalia, M., & Bereiter, C. (1991) Literate Expertise. In K. A. Ericsson & J. Smith, J. (Eds.), Toward a general theory of expertise. Prospects and limits. (pp. 172-194). Cambridge: Cambridge University Press.

Scardamalia, M., & Bereiter, C. (1991) Higher levels of agency for children in knowledge building: A challenge for the design of new knowledge media. The Journal of The Learning Sciences, 1, 37-68.

Scardamalia, M., & Bereiter, C. (1993) Technologies for knowledge-building discourse. Communications of the ACM, 36, 37-41.

Scardamalia, M., & Bereiter, C. (1994) Computer support for knowledge-building communities. The Journal of the Learning Sciences, 3, 265-283.

Scardamalia, M., & Bereiter, C. (1996) Adaptation and understanding: A case for new cultures of schooling. In S. Vosniadou, E. De Corte, R. Glaser, & H. Mandl (Eds.) International perspectives on the psychological foundations of technology-based learning environments. (pp. 149-163). Mahwah, NJ: Lawrence Erlbaum.

Scardamalia, M., Bereiter, K. & Lamon, M.(1994). The CSILE project: Trying to bring the classroom into world 3. In Kate McGilly (ed. Classroom lessons: Integrating Cognitive Theory and Classroom practise, 201-228. Cambridge, MA: Bradford Books/MIT Press.

Schlack, M. (1991). IS puts Notes to the test. Datamation, 37, 15, 24-26.

Schrage, M. (1990). Shared Minds. New York: Random House.

Schwartz, D. L. (1995) The emergence of abstract representations in dyad problem solving. The Journal of the Learning Sciences, 4, 321-354.

Schwartz, J. L. (1995) Shuttling between the particular and the general: Reflections on the role of conjecture and hypothesis in the generation of knowledge in science and in mathematics. In D. N. Perkins, J. L. Schwartz, M. M. West, & M. S. Wiske. (Eds.) Software goes to school. (pp. 93-105). Oxford: Oxford University Press.

Sfard, A. 1998. On two metaphors for learning and the dangers of choosing just one. *Educational Researcher* 27(2), 4-13.

Seymour, S.R. (1994). Operative computer learning with cooperative task and reward structures. Journal of Technology Education, 5 (2).

Shabo, A.; Nagel, K., Guzdial, M. & Kolodner, J. (1997) JavaCap: A collaborative case authoring program on the WWW. In R. Hall, N. Miyake & N. Enyedy (Ed.) Computer Support for Collaborative Learning ´97. Proceedings of The Second International Conference on Computer Support for Collaborative Learning. December 10-14, 1997. Toronto, Ontario, Canada, 241-250.

Shaffer, D. W. (1997) Design, collaboration, and computation: The design studio as a model for computer-supported collaboration in mathematics. In R. Hall, N. Miyake & N. Enyedy (Ed.) Computer Support for Collaborative Learning ´97. Proceedings of The Second International Conference on Computer Support for Collaborative Learning. December 10-14, 1997. Toronto, Ontario, Canada, 250-255.

Shlechter, T.M. (1990). The relative instructional efficiency of small group computer-based training. Journal of Educational Computing Research, 6, 329-341.

Silverman, Barry G. (1995). Computer Supported Collaborative Learning (CSCL). Computers Education, Vol. 25 (3), 81-91.

Steeples, C., Goodyear, P. & Mellar, H. (1994). Flexible learning in higher education: the use of computer-mediated communications. Computers and Education 22 (1/2), 83-90.

Sutton, S. A. (1996). Planning for the Twenty-First Century: The California State University. Journal of the American Society for Information Science, 47 (11), 821-825.

Suthers, D.D. (1998). Computer aided education and training initiative. Technical Report (12 January 1998)

Suthers, D., Erdosne Toth, E., & Weiner, A. (1997). An Integrated Approach to Implementing Collaborative Inquiry in the Classroom. *Computer Supported Collaborative Learning (CSCL'97),* December 10-14, 1997, Toronto.

Suthers, D and Jones, D. (1997). An Architecture for Intelligent Collaborative Educational Systems. *8th World Conference on Artificial Intelligence in Education (AIED'97),* August 20-22, 1997, Kobe.

Suzuki, H. & Hiroshi, K. (1997) Identity formation/transformation as the process of collaborative learning through AlgoArena. In R. Hall, N. Miyake & N. Enyedy (Ed.) Computer Support for Collaborative Learning ´97. Proceedings of The Second International Conference on Computer Support for Collaborative Learning. December 10-14, 1997. Toronto, Ontario, Canada, 280-288..

Sharan, S., & Shachar, C. (1988). Language and learning in the cooperative classroom. New York: Springer-Verlag.

Sharan, Y., & Sharan, S. (1992). Expanding cooperative learning through cooperative classroom. New York: Teachers College Press.

Slavin, R.E. (1987). Cooperative learning: Where behavioral and humanistic approaches to classroom motivation meet. Elementary School Journal, 88, 9-37.

Slavin, R.E. (1992). When and why does cooperative learning increase achievement? In R. Hertz_Lazarowitz & N Miller (Eds.). Interacting in cooperative groups. The theoretical anatomy of group learning (pp. 145-173). New York: Cambridge University Press.

Slavin, R.E. (1995). Cooperative learning: Theory research and practice. Boston: Ally & Bacon.

Slavin, R. E. (1997). Research on cooperative learning and achievement: A quarter century of research. Paper presented at the Annual Meeting of Pedagogical Psychology, Frankfurt, September.

Talamo,A. (ed.) (in press) Apprendimento e comunicazione didattica: il ruolo delle nuove tecnologie, Firenze, La Nuova Italia.

Talamo, A., Pontecorvo, C., (1997) *Constructing Hypermedia: skills and processes in a communication context*, Poster presented at the 7th European Conference for Research on Learning and Instruction, Athens August, 26-30 1997.

Talamo, A. & Menotti, E.(in press). Interazione e metacognizione nella costruzione di ipertesti, *Ricerche di Psicologia*.

Talamo, A. & Pontecorvo, C. (in press). New Technologies and The Changing of Learning Context. *Journal of Educational Computing Research*.

Tuomisto, A. (1994) Computer Supported Work: A Perspective. Proceedings of the 17th IRIS conference (Information systems Research seminar In Scandinavia), Finland, August, pp. 543-552.

Turkle, S. (1984). The second self. New York: Simon & Schuster.

Turkle, S. 1984. The Second Self: Computers and the Human Spirit, London Granada.

Vandenbosch, B. & Ginzberg, M.J.(1996/97). Lotus Notes and collaboration: Plus ca change. Journal of Management Information Systems, 13 (3) p 65-82

Vosniadou S., (1994) From cognitive theory to educational technology, in Vosniadou,S., De Corte, E. Mandl, H. *Technology-Based Learning Environments*, Berlin, Springer-Verlag, pp.

11-18.

Vosniadou, S., DeCorte,E., Glaser, R. & Mandl, H. (Eds.) (1996). International perspectives on the psychological foundations of technology-based learning environments. Hillsdale, NJ: Lawrence Erlbaum.

Vygotsky, L. (1934/1994). The development of academic concepts in school aged children. In R. van der Veer & J. Valsiner (Eds.). The Vygotsky reader (355-370). Oxford: Blackwell. (Originally published in Russian 1934)

Vygotsky, L. (1935/1994). The problem of the environment. In R. van der Veer & J. Valsiner (Eds.). The Vygotsky reader (338-354). Oxford: Blackwell. (Originally published in Russian 1935).

Vygotsky, L.S. (1978) Mind in Society: The Development of Higher Psychological Processes. Cambridge, MA: Harvard University Press.

Walther, J.B., Anderson, & J.F.,Park, DW.(1994). Interpersonal effects in computer-mediated interaction. Communication Research, 21 (4) 460-488.

Wang, D. & Johnson, P. M. 1994. Experiences with CLARE: A Computer-supported Collaborative Learning Environment. International Journal of Human Computer Studies 41(6), 851-879.

Webb, N. 1989. Peer interaction and learning in small groups. International Journal of Educational Research 13, 21-40.

Webb, N.M. (1992). Testing a theoretical model of student interaction and learning in small groups. In R. Hertz Lazarowitz & N. Miller (Eds.), Interaction in cooperative groups: The theoretical anatomy of group learning (pp. 102-119). New York: Cambridge University Press.

Webb, N.M. & Palincsar, A.S. (1996). Group processes in the classroom. In D.C. Berliner & R.C. Calfee (Eds.), Handbook of educational psychology. New York: Simon & Schuster MacMillan.

Woodruff, E. & Brett, C. (1993) Fostering scholarly collaboration in young children through the development of electronic commenting. Research in Education, 50, 83-95.

Woolley, J.D.(1995) Chidren's Understanding of Fictional versus Epistemic Mental Representations: Imagination and Belief: Child development 66 (4), 1011-21.