Computer-Supported Collaborative Learning: Issues for Research

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Abstract

This paper is an attempt to summarise the current trends in collaborative learning research. This paper introduces and characterizes a number of collaborative learning systems, synthesises the findings of collaborative learning research into many dimensions, discusses the applicability and effectiveness of collaboration for the given scenario, and finally presents a collaborative learning research proposal to implement the scenario along with a number of research opportunities in collaborative learning.

Overview

Collaborative learning deals with instructional methods that seek to promote learning through collaborative efforts among students working on a given learning task. Computer Supported Collaborative learning (CSCL) enhances learning in a dynamic fashion, where the system that delivers the collaborative environment takes an *active* part in analysing and controlling collaboration [1]. On the other hand, Computer-Supported Cooperative Work (CSCW) deals with collaboration in a *passive* fashion, where the system that delivers the collaborative environment does not attempt to exercise active control of the collaborative interactions.

Depending on the type of collaborative tasks to perform, CSCL could be employed to address *concept learning*, *problem solving*, and *designing*. Concept learning deals with a goal as a single entity while the other two deal with a goal in terms of sub-goals. Further, *designing* is distinguished from *problem solving* in the sense that the number of solutions in *problem solving* is finite and computationally easier to represent.

Another major factor that regulates collaboration is the theory of learning, based on which collaborative interactions could be categorized into *socio-cognitive, socio-cultural, and situated cognition* (Dillenbourg *et al.* 1994).

This paper also categorizes collaborative learning along the dimensions of the design of a collaborative environment, the types of roles for the peers and the domains where collaborative learning is most effective.

The "WHY" section consolidates the motivation behind computer-supported collaborative learning research. The section on "SYSTEMS" identifies some of the present day collaborative learning systems and categorizes them along the dimensions identified earlier. This is followed by a "RESEARCH" section that contains a research proposal from the author and a number of research opportunities pertaining to collaborative learning.

Why Collaborative Learning?

Collaborative learning provides an environment to enliven and enrich the learning process. Introducing interactive partners into an educational system creates more realistic social contexts, thereby increasing the effectiveness of the system. Such an environment would help sustain the student's interests and would provide a more natural learning habitat.

As Piaget (Piaget 1928; 1932) pointed out, collaborative learning has a major role in constructive cognitive development. His theory is consistent with the other popular learning theories (Vygotsky 1978; Fox & Karen ; Thomas & Funaro 1990) in emphasising the importance of collaboration. Piaget felt that interaction between peers is equally shared. This contrasts adult-child or teacher-student interactions, where usually the former is in control and the latter characteristically follows what the former professes, thus not following his/her own natural learning process.

[1] CSCL is used interchangeably with Computer-Based Collaborative Learning (Taylor *et al.* 1990), Collaborative Intelligent Educational Systems (Cumming & Self 1989a; 1989b), Collaborative Intelligent Tutoring Systems (Kumar 1992), Intelligent Collaborative Learning Systems (McManus & Aiken 1993), Multi-Agent Cooperative Learning (Robertson, Zachary, & Black 1990; Galliers 1988; 1989) and Peer Learning (Chan & Baskin 1988; Chan 1991; 1993; VanLehn & Ohlsson 1994).

In one-to-one computer-based tutoring, the system interacts with one student and attempts to personalise the tutoring to the needs of the student. On the other hand, in a one-to-many collaborative learning environment, the system interacts with a group of students, imparting the subject knowledge using a collaborative learning strategy. It should be noted that a one-to-N environment is not a combination of "N" one-to-one learning environments.

Collaborative learning presents an environment in which a student interacts with one or more collaborating peers to solve a given problem. The interactions among the students are monitored and controlled by a collaborative learning System. The Collaborating System is connected to the workstations from which students would interact. A typical one-to-one learning system and a computer-supported collaborative learning environment are contrasted in Figure 1.

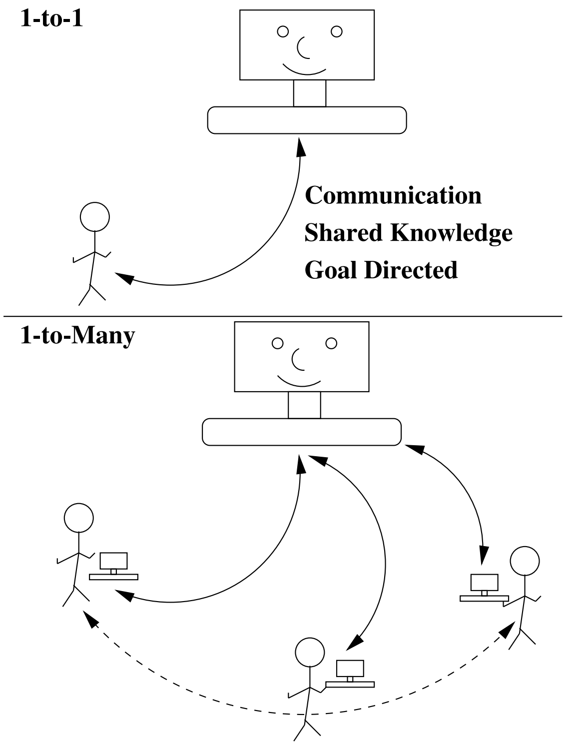

Figure 1: 1-to-1 Vs CSCL

A collaborative learning system concentrates on refining and integrating the learning process and the subject knowledge of the students with the help of the collaborative partners. The promise of collaborative learning is to allow students to learn in relatively realistic, cognitively motivating and socially enriched learning contexts, compared to other tutoring paradigms like socratic learning, discovery learning, integrated learning, etc. For instance, the student might *discuss* the strategies to solve a given problem in a problem-solving domain like trigonometry or *practice* the colloquial usage of a foreign language in a computer-aided language learning system. With CSCL, the student can discuss these strategies with a group of fellow students who advise, motivate, criticize, compete, and direct the student towards better understanding of the subject matter.

There are a number of experimental studies and implemented systems available in the literature to emphasise the effectiveness of collaboration. An experiment on *Constructive Interaction* by Naomi Miyake (Miyake 1986) confirms that in the learning process the bulk of *Constructive Criticisms* occur while learning in collaboration. The experiment showed that about 80% of *self-critiquing* (reflection) took place during collaborative learning compared to 20% which took place when students were learning alone. Self-critiquing is one of the major contributors to the effectiveness of collaborative learning. This experiment showed that the learners might have missed the opportunity for better understanding if they had not collaborated. Misconceptions in peers could be put to effective use when an appropriate peer is found to handle the misconceptions. Durfee et al. (Durfee, Lesser., & Corkill 1989) showed that the performance of a network of problem solving agents is better when there is some inconsistency among the knowledge of each agent. Thus a set of non-overlapping misconceptions among collaborating peers could be put to effective use in collaborative learning.

Collaboration experience can also facilitate planning and problem solving. Blaye et al. (Blaye *et al.* 1990; Blaye 1989) showed that children who had previously worked as collaborative pairs on the task of planning and problem solving were twice as successful as children who had had the same amount of experience working alone.

Chan and Baskin (Chan & Baskin 1988; Chan 1991) implemented a collaborative learning environment called *Integration-Kid* for the domain of symbolic integration. In *Integration-Kid* the student collaborates with a simulated *companion* to learn integration. The system provides more dimensions of learning, higher motivation, and better attitude toward learning through collaboration.

There are a number of other empirical studies and tools that illustrate the advantages of collaborative learning. These theories, experiments, and results indicate the effect of collaboration on human cognition and the need for collaborative techniques in learning environments.

Collaborative Learning Systems and Dimensions

Recently there has been a surge of interest in the field of CSCL. As a result, a number of CSCL systems are being developed. Here we list some of the CSCL systems along with a short description. This section provides the base from which the paper attempts to synthesise the dimensions of CSCL research. The systems described here will be referred to in the later sections.

ODISSEUS is an apprenticeship expert system that refines its knowledge base by watching a human expert solving problems. Thus, the human expert collaborates with the system to make the system learn. The expert's behaviour is recorded as an example and the system applies explanation-based learning to learn from the example (Wilkins 1988).

LEAP is a learning system that explains why a VLSI circuit works for a given input signal. The user can reject the proposed explanation and redefine the circuit. Accordingly, LEAP modifies its rule-base (Mitchell, Keller, & Kedar-Cabelli 1986).

SHERLOCK is an apprenticeship 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 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 & Lesgold 1993).

MEMOLAB is a learning environment that illustrates the distribution of roles among several agents. The learner solves problems interacting with an expert. The system provides assistance using another agent (tutor) which also monitors the interaction. The distribution of roles are conceived in such a way that the agents are independent of the teaching domain and hence can be reused to build other learning environments (Dillenbourg, Mendelsohn, & Schneider 1994).

BOOTNAP is an artifact-based collaborative learning system. It proposes to support human-computer interaction techniques that are functionally equivalent to the gestures observed in human-human social grounding. The system is still in its developmental stages (Dillenbourg 1995).

PREP is an acronym for *Work in PREParation*, a writing tool developed at the Carnegie Mellon University. PREP uses a two-dimensional grid of text, similar to a spread sheet, on which the peers would work individually. The text is split into horizontal segments that each peer would handle. The peers are supposed to comment on, rewrite or edit the text in their segment. In addition they are allowed to browse through other segments handled by other peers. Thus, using PREP, peers develop individual parts of the text and also review other's work. PREP is found useful in dealing with small-grain writing problems such as style, sentence clarity and paragraph structure, and less for large-scale problems like overall organisation and document structure (Neuwirth *et al.* 1990).

ShrEdit is a collaborative text editor used primarily for studies of group behaviour (McGuffin & Olson 1992).

Integration-Kid is a learning companion system (student-teacher-companion) in the domain of symbolic integration, covering a complete but short course at the level of first year undergraduate. Either the student or the system generated companion are responsible for solving a given problem. One decides the problem solving steps while the other executes them. In the case where both the student and the companion cannot solve the problem, the teacher will interrupt to help (Chan 1991; 1993).

Three's Company is an extension of Integration-Kid that includes one more companion agent. Using the additional companion, the system analyses the motivation of the student if his/her performance lies between the two companions (Lin 1993).

Reciprocal-Kid is a Lisp Programming tutor where the programming task is decomposed into planning, executing and critiquing. Reciprocal-Kid is built on top of a scaffolding system called Petal (Bhuiyan, Greer, & McCalla 1992). The system also supports a tutor who gives advice and play the final judge if conflicts between different agents arise (Chan 1993).

People Power is a computer supported collaborative system where the colearner acts as a collaborator of the student. People Power contains a microworld in which the student can create an electoral system and simulate an election. The co-learner acts as a proposer or a critique to prove that some changes in a country could lead to a gain of seats for a particular party (Dillenbourg & Self 1992a).

Distributed West is a reimplementation of the classic West system. Here the student plays against a computer opponent in trying to reach the destination ahead of the opponent. The system provides a collaborative setup where two real peers can play the game against each other or a small group of peers combine together to play against the system (Chan 1993).

QUILT is a writing system that supports different styles of collaboration. QUILT imposes writing structure with regard to member's social roles or authority. QUILT encourages groups to establish well-defined social and authority structures with respect to coauthored documents. For instance, participants can take the roles of *co-author, commentator and reader* (M. D. P. Leland & Kraut 1988) .

Rescue is a role playing game system. The student takes up an assigned role and interacts with other agents in a given situation. The student constructs the interactions using a menu-based language and explores the given environment to achieve the task (Chan 1993).

These are some of the collaborative learning systems available from the current literature. Being a new field, many CSCL techniques are still being developed. It is interesting to note that most of the systems listed here use Artificial Intelligence techniques in some form but only a few systems use AI techniques to address collaborative learning per se.

Dimensions of Collaborative Learning

Collaborative learning research can be viewed from seven different perspectives: control of collaborative interactions, tasks of collaborative learning, theories of learning in collaboration, the design of collaborative learning environment, the roles of the peers, the domains of collaboration and the teaching methodologies that inherently support collaboration. These seven are treated as the seven essential dimensions of collaborative learning that should be addressed in the design, development and use of CSCL systems.

Control of Collaborative Interactions The control of collaborative interactions refers to the mode of delivery of the collaborative environment by the system. A collaborative learning system can take an active part in analysing and controlling collaboration or act just as a delivery vehicle for collaboration. Depending on the amount of control embedded within a system, collaborative learning systems can be classified as *active* or *passive* systems or anywhere in the range between active and passive.

CSCL accommodates active collaboration while CSCW is rather passive. CSCL could be considered as a superset of CSCW since it not only provides the delivery vehicle for collaborative interactions that is provided by CSCW, but also provides the additional controls required to guide collaborative learning in an active fashion, based on the requirements of the peers involved in learning. CSCW simply provides the means for collaboration and it is left to the collaborators to make use of the means in the most effective way possible, while CSCL not only provides the means for collaboration but can also analyse and direct the collaborative interactions based on the content of collaborative interactions.

Tasks of Collaborative Learning In a given collaborative learning environment the collaborating peers could be faced with different types of tasks to perform. The tasks could be enumerated independently of the subject domain that has been taught. This paper identifies three types of tasks that are implementable within a collaborative learning setup.

- collaborative concept-learning tasks
- collaborative problem-solving tasks
- collaborative designing tasks

Of the three tasks, *concept learning* is a fact-based task while the other two are analysis/synthesis-based tasks. Fact-based and analysis/synthesis-based tasks provide a clear distinction among collaborations based on the grain-size of task being handled by a peer. In a fact-based collaboration, the peers have a single goal and all the peers attempt to collaborate towards the single goal. For instance, systems like Rescue and PeoplePower have a single goal that is not explicitly split into subgoals. On the other hand, a analysis/synthesis-based task typically splits the given goal into sub-goals and the peers handle each subgoal independent of each other. For instance, Integration Kid splits the given integration problem into sub-problems and attempts to solve the sub-problems.

Thus concept learning carries with it the expectation of a singular purpose and a seamless integration of the parts, as if the conceptual object were produced by a single effort (Smith 1994). For example, the sections of a well-written document would be so consistent, it would be very difficult for the reader to distinguish the authors of the different sections. Problem solving and designing are less stringent in their demands for integration. They require that the peers carry out their individual subgoals in accord with some larger goal and they are not required to know in detail what goes on in the other parts of the goal, so long as they carry out their own assigned subgoals satisfactorily (Smith 1994).

Theories of Learning and Cognition in Collaboration Dillenbourg (Dillenbourg *et al.* 1994) identifies three different theories of learning that could be employed in collaborative learning systems:

- socio-constructivist theory
- socio-cultural theory
- shared cognition theory

Each theory relates the student's learning to a typical learning environment. These three approaches are classified as *cognitive developmental approaches* that focus on the interactions among peers around appropriate tasks in a given environment that would increase the mastery of critical concepts.

- **Socio-constructivist theory** advocates that students master new approaches of learning through interacting with others (Doise 1990). This theory is an extension of Piaget's (Piaget 1928; 1932) theory that focused on the reasons for cognitive developments in individuals. In socio-constructivist theory, emphasis is given to interactions rather than actions themselves. A given level of individual development allows participation in certain social interactions which produce new individual states which, in turn, make possible more sophisticated social interactions, and so on (Dillenbourg *et al.* 1994).

  The socio-constructivist approach focuses on the individual's development with respect to the social interaction, without really differentiating or identifying the underlying factors that enhance collaborative learning. Here the social interaction is assumed as a black box that boosts collaborative learning.

  The experimental setup for the socio-constructivist approach follows a three stage process of pre-test, individual or collaborative learning and post-test. The differences between individual and collaborative learning are identified with respect to the difference between the performances on the pre- and post-test. A number of empirical studies have been reported to validate this approach (Doise & Mugny 1984; Blaye *et al.* 1990; Blaye 1989; Durfee, Lesser., & Corkill 1989; Gasser 1991).

- **Socio-cultural theory** focuses on the causal relationship between social interaction and the individual's cognitive development. This approach is derived from Vygotsky's zone of proximal development (Vygotsky 1978). In this approach, each internal cognitive change is mapped onto a causal effect of a social interaction. In Vygotsky's own words:

  > The Zone of Proximal Development is the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers (Vygotsky 1978).

  This essentially means that a learner would use the technique(s) that are learned during the collaborative effort with the companion when the learner tries a similar problem independently. That is, *self review* by the student is the internalization of *peer review*. The zone of proximal development defines metaconceptions that might evolve as learned concepts after a period of social interactions. Thus, the inter psychological processes are internalized during social interactions. Based on this theory, Dillenbourg and Self (Dillenbourg & Self 1992b) developed a computational model. In general, the socio-cultural approach supports collaboration as the means that would prove to be the catalyst to help the metaconceptions mature into learned concepts.

- **Shared cognition theory** is different from the other two theories in the sense that the environment in which learning takes place is given the focus rather than the environment-independent cognitive processes. The environment consists of both physical context and social context. The previous two approaches attributed the learning only to the physical context. But the shared cognition approach places the focus squarely on the social context that is claimed to make the collaborations happen and not just the presence of the collaborators.

  Shared cognition aims at letting the peers learn knowledge and skills in contexts where they are applicable (Brown, Collins, & Duguid 1988; Lave & Wenger 1991). Some advantages of the situated cognition approach are:

  - By linking together specific contexts and the knowledge to be learned, peers learn conditions under which the knowledge should be applied.
  - Situations foster creative thinking. Peers often learn how the knowledge they have can be applied in new situations.
  - Situatedness leads to the acquired knowledge being more practical in nature.

According to this approach, collaboration is viewed as a process of building and maintaining a shared conception of a problem, thus ensuring a natural learning environment.

Design of Collaborative Learning Environment
A variety of peer learning environment designs to support effective collaborative learning has been attempted or proposed. The backbone of collaborative learning is the willingness of the peers to participate in collaboration in a constructive sense. This has been studied by a number of educational psychology researchers (Madden & Slavin 1983; Slavin 1978) who confirm that the peers in collaborating classes felt that their peers wanted them to learn. Slavin (Slavin 1990) reports studies that confirm the willingness of peers to make the collaborative learning efforts succeed and the improvement in social status of the peers who achieved better than other peers.

Effective collaboration requires appropriate pairing of collaborating peers. There have been studies to identify the factors involved in combining peers. Slavin (Slavin 1990) reports a study by Kuhn (Kuhn 1972) who found that a small difference in cognitive level between collaborating peers was more conductive to cognitive growth than a larger difference. This supports the view that the collaborative peers should have almost equal knowledge levels to make the collaboration constructive. However, the study by Azmitia (Azmitia 1988) found that when novices were paired with experts on a model building task they improved significantly while equal ability pairs did not. The contradiction in pairing of knowledge levels could be because of the difference in domains or characteristics of peers or the experimental setup. Azmitia's view is further supported by Rogoff (Rogoff 1990; 1991) who found better results with adult-child than with child-child pairing. She also identified the intermediate variable that explains these variations. She found that effective adults involved the child in explicit decision making while skilled peers tended to dominate the decision making. Thus, a collaborative learning environment should also possess mechanisms to identify the appropriateness of peers to collaborate with each other.

There have also been studies to support collaborative learning conducted from the computational viewpoint. For instance, Blaye et al. (Blaye *et al.* 1990) use a (peer1-peer2-system) environment to solve information gathering and planning problems. While one peer attempted to solve the problems the other watched the problem solving process and provided critiques and suggestions. Chi et al. (Chi *et al.* 1989) present a restricted environment where the learner is forced to explain an example to himself or herself, thus leading to reflection.

The combination of tasks and the number of peers involved in the learning is determined by the subject domain being taught, the learning theory adopted, and the capability of the system. The following list presents a variety of collaborative environment designs:

- Two or more peers collaborating with each other using the computer as a mediating tool. The system does nothing but provide the communication channels for collaboration without playing an active role.
- Two or more peers collaborating with each other using an active tutor that controls and directs collaborative interactions.
- Two or more peers working together on a problem at the same workstation, using the tutor in much the same way as when a peer works alone. The peers could be intelligently grouped based on the background knowledge about the peers.
- Two or more peers working together on a problem from networked machines where peers take turns carrying out the next action. Communication windows are available so that students can send advice, suggest alternative actions, comment on their partner's actions, etc. Peers could work in reciprocal teaching mode or competitive fashion. On the other hand, one peer could act as a coach while the other would attempt to solve the problem.
- Two or more peers working together with at least one of the peers being simulated by the system. Peers can take turns carrying out actions with a simulated peer. The simulated peer can carry out actions automatically or on demand. Simulated peers can be selected from a library of student models. VanLehn et al. (VanLehn & Ohlsson 1994) and Kumar (Kumar 1992) discuss the generation, utility and control of simulated peers in collaborative learning.

Collaborative learning research has not identified formalisms prescribed for an ideal collaborating environment design for peers. It is left as a subjective assessment and prescription depending on the application, peers, and collaborative environment.

Roles in Collaborative Learning Environment
In a collaborative learning environment, where the goal is split into subtasks to be carried out by individual peers, it is often found that the peers are assigned *roles*, that are natural and directly applicable in the given domain. Blaye et al. (Blaye *et al.* 1991) suggest the

roles of *executor*, the one who solves the problem and *reflector*, the one who observes and comments on the problem solving.

In general, a collaborative learning environment can have the following set of roles: *decomposing, defining, critiquing, convincing, reviewing, and referencing.* For a peer, the system should maintain a model of each of these roles (McCalla 1990).

Decomposing refers to the job of splitting the given problem into tasks. Each task is a logical sub-unit of the given problem. Each of the tasks can be further split into a number of goals, which the collaborative learning system recognizes. The goals are the learning objectives for the student. A list of goals comprise a task. Proposing a goal from a task is referred to as *defining.* The goals defined can be traced from the task state to the goal state. *Critiquing* essentially means countering the hypothesis proposed by a peer with an alternative hypothesis. *Convincing* is an act of comparing a number of hypotheses and supporting one of them. *Reviewing* is the job of ensuring that the collaborative interaction leads to constructive learning. The reviewer summarizes the actions taken in the collaborative session for a particular goal. *Referencing* is the job of providing facts and related material, whenever requested by a peer.

Galliers (Galliers 1988; 1989) describes a formal approach using logic to model the collaborative roles. Galliers presents a framework to represent conflicts and convincing in addition to many other collaborative processes.

Blandford (Blandford 1994) presents a list of actions that are applicable for a conflict-resolution based collaborative learning system, where it is possible for the peer to execute different types of actions related to *imparting disagreement (I disagree), eliciting justification (Why do you believe that), imparting justification (...because...), imparting alternative belief, eliciting agreement (don't you agree?) and eliciting confirmation (do you really believe that),* etc.

Dansereau (Dansereau 1988) found that peers working on structured *cooperative scripts* can learn technical material or procedures far better than can students working alone. In this method, peers take roles as recaller and listener. They read a section of text, and then the recaller summarises the information while the listener corrects any errors, fills in any omitted material, and thinks of ways both students can remember the main ideas. This mirrors the peer-tutoring findings of Webb (Webb 1985) who found that the peers who gained the most from collaborative learning were those who provided elaborated explanations to others. Explanations reinforce learning. Baker (Baker 1991) found that explanations are not offered from the explainer to the explainee instead constructed jointly by both peers through collaborative interactions. Chi et al (Chi *et al.* 1989) found that helping peers via explanation should in turn enhance the helper's learning. Thus, explaining or elaboration is found to be a catalyst for an effective collaborative learning process. There could be role(s) to extract explanations from the collaborating peers. O'Malley (O'Malley 1987) also emphasises the importance of the selection of roles for the peers. She reports that constructive collaboration takes place only if the peers take appropriate roles. For instance, the peer who has to say more would take the role of task-doer while the other peer would become an observer, monitoring the situation (Dillenbourg *et al.* 1994).

The design of a collaborative learning environment should also consider the *number or group size* of collaborating peers. Most of the experiments are conducted with small numbers of peers to reduce the complexity of deriving inferences. It is natural to assume that the number of peers is dependent on the requirement of the collaborative learning task.

Domains of Collaborative Learning In general, collaborative learning is found effective in domains where peers engage in *skill acquisition, joint planning, categorization, and memory tasks.* The idea is that peers learn the prerequisites of the topic to be learned and reinforce/internalize the topic using the collaborative environment. There have been a number of studies that propose collaborative learning to help learners understand complex tasks. For example, Miyake(Miyake 1986) shows that the complex understandings of the working of a tailoring machine is better understood when the peers interacted collaboratively and attempted to understand the problem. O'Malley (O'Malley 1987) reports that spontaneous division of work occurs in collaborative learning in the domain of understanding the UNIX C-shell command interpreter. Connah et al. (Connah, Shiels, & Wavish 1988) believe that the cooperative behaviour supports higher cognitive learning, based on a simulated physical world domain.

Thus, in collaborative learning domains, the domain knowledge to be imparted is complex, hierarchical, and requires deep understanding of each level in the hierarchy. It is difficult to observe a conceptual change if the task is purely procedural and does not involve much understanding. Some domains are less *shareable* than others, like solving anagrams since the processes involved are not easy to verbalise. Domains like air-traffic control are inherently distributable and hence can be effectively learned using collaborative learning (Dillenbourg *et al.* 1994).

Taylor (Taylor *et al.* 1990) reports a collaborative learning domain of *secondary school physics*, where the peer predicts the outcome of a given problem. Based on the success reported by Taylor, it is assumed that any simulatable domain could be a good candidate for collaborative learning.

The domain of computer-aided language learning inherently supports collaborative learning because language is learned in situations that are collaborative. From these discussions, it is observed that the subject domain plays an important role in deciding the success and effectiveness of collaboration in learning.

Collaboration in some domains requires prerequisite knowledge using which peers could reinforce their domain knowledge. Lasarova and Tzoneva (Lasarova & Tzoneva 1988) in their experiment on Logo-oriented cooperative learning conclude that self-regulated learning of a pupil, followed by a cooperative learning session with the teacher is more rewarding. This experiment shows the strong underlying need to use collaborative learning as a follow up for regular learning to reinforce the learned concept as well as to remove fundamental misconceptions. On the other hand, collaborative learning could also be used to teach the domain knowledge the first time that could later on be reinforced. For instance, teaching conversational knowledge could use collaborative learning as the starting point.

Tutoring in Collaborative Learning A number of tutoring methodologies are identified that inherently support collaborative learning.

Practice The peer is asked to apply a goal learned on a specific problem.

Socratic Learning The student is prompted with a series of questions about the domain, to which the student reacts with a hypothesis or a question of his/her own.

Learning by Teaching This methodology supports learning by having the student teach the system, a variation on the use of a simulated student. (Palthepu, Greer, & McCalla 1991) and (Nichols 1994) have built systems to support *learning by teaching*.

Situated Learning In this methodology, the student becomes a participant in a sociocultural practice, where the learning skills and the social process go together, as practiced in Legitimate Peripheral Participation (Wenger 1988). The degree of situatedness depends on the environment that simulates the collaboration.

Negotiated Learning In this methodology, the student and the system negotiate mutually acceptable learning goals (Moyse & Elsom-Cook 1992; McCalla 1990). The student model is expected to keep track of goals of mutual knowledge.

Discovery Learning The student explores an environment specially crafted to encourage learning. Peers could take individual roles in discovering the environment.

Table 2 projects the collaborative learning systems in terms of the six dimensions. The seventh dimension, *tutoring* is not included in the table. Out of the 14 systems tabulated here, 11 are classified as CSCL systems and the other 3 as CSCW systems. Most of the CSCL systems handle problem solving (8 out of 11) tasks and socio-cultural (7 out of 11) approach. In general, CSCL systems represent the domain knowledge of a peer as an overlay of that of an expert thus providing the roles of *expert* or *tutor*. The roles of the CSCL systems are predominantly domain-dependent.

Collaborative Learning Research - Proposal and Opportunities

Based on the state of the art in collaborative learning, this paper proposes a methodology to design and implement a generic collaborative learning tool. The components of the tool and the technology required for the development of the tool are discussed in brief. This is followed by an outline of a number of research opportunities in the area of collaborative learning.

Collaborative Learning Research Proposal

This research proposal identifies two stages within collaborative learning:

- pre-collaboration tasks
- core research in collaborative learning

Precollaboration Tasks It is essential to identify the tasks that are to be satisfied before starting a collaborative learning session in order to ensure reliability and effectiveness of collaborative learning in addition to bootstrapping the collaborative learning session.

The peers should identify an appropriate domain for collaboration. Some domains are suitable for collaboration and some or not. Within a given field of study there could be a number of domains suitable for collaborations. There should be a mechanism to recognize the domain and validate the effectiveness of collaboration for this domain.

Identifying peers and verifying their suitability for collaboration is yet another pre-collaboration task.

The peers should be available over the computer network that supports collaboration. In addition, their suitability for collaboration with respect to the characteristics of other peers and availability of resources should be verified. This is important to eliminate some of the shortcomings of collaborative learning. For instance, the free-rider effect, where an opportunistic peer would get the most out of the collaborative learning session without really contributing to the benefit of the other peers, could be controlled. Similarly, individual tastes and styles of the peers could be taken into consideration to make collaboration more personalized.

In terms of resources, the network on which collaboration takes place and the tools that are used should be identified. For instance, if the network load is too high to support real-time collaboration, then the system should be able to withdraw from real-time collaboration. Compatibility of the collaborating tools used by the different peers should be verified before collaborative sessions commence.

It is often believed that collaboration is most effective when the peers have the prerequisite knowledge to collaborate. In this case, collaboration is used to reiterate/internalize what the peers have already learnt.

Core Research The pre-collaboration tasks concentrate more on the practicality of collaboration and not on the technical details primarily because of the lack of technology. With the recent advancements in the fields of distributed artificial intelligence, student modelling and diagnosis, knowledge representation, distributed cognition, etc., it is now possible to address most of the core research areas of collaborative learning in terms of the fundamental techniques that are derived from these fields.

- ❑ **Interface** for collaboration should support a language through which the collaborating peers interact. The language should be task specific and expressive enough to address the questions pertaining to the given domain. The interface should also monitor the time lag between communications and responses of the peers. For instance, in a real-time collaborative session, the delay between the responses of the peers should be handled appropriately. The delay could have been caused either by the network load or by the actual delayed response of the peers.

- ❑ **Modelling** of the collaborating peers is an interesting and challenging research problem that would involve representation of the collaborative traits like *conflicts* and *resolution*. The roles of the collaborating peers could be modelled depending on the characteristics of the roles and the depth of the modelling process. It is also important to model the collaboration processes among peers at various levels of granularity. This would be of use in diagnosing and explaining the collaboration processes. The granularity levels of the collaborative student modelling should model the factors that are prevalent in collaboration. For instance, social factors like gender differences and educational background differences could be used to predict the effectiveness of collaboration. Similarly, domain-dependent factors like *conflict in terms of a hypothesis* should be modelled so that the peers understand the direction of collaboration.

- ❑ **Knowledge representation** for CSCL could use the present day AI technology like scripts, semantic networks, frames, CYC, etc. Galliers (Galliers 1988; 1989) use first order logic to represent collaboration factors like *conflicts*.

- ❑ **Coordination of collaboration** is a major process in collaborative learning. For instance, management of the different roles assigned to the peers is a research topic by itself that addresses questions like *who responds next* or *which role should initiate the response*, etc. Similarly the processes of collaboration should be evaluated based on a set of pedagogical guidelines that ensure that collaboration takes place at an appropriate pace, and with positive interactions from all the peers. Similarly, the system should be able to provide different tutoring techniques to suit the tastes of the collaborating peers. Determination of an appropriate tutoring technique and handling collaboration using the same is another major core research in collaborative learning.

Opportunities For Research

While the field of "Education" has its impact and findings related to collaborative learning, "Computer Science" presents a completely different view of the collaborative learning research. Traditionally, educationists tend to view collaborative learning as a black box. In other words, educational researchers controlled several independent variables and studied collaboration in terms of these variables (Dillenbourg *et al.* 1994). Computer Scientists tend to represent the internals of collaboration thus focussing on the roles these variables play in controlling the effectiveness of the learning environment. This paper presents a number of research avenues related to CSCL that are open for investigation.

Identifying domains for collaboration and applying the appropriate collaborative learning techniques for a given domain is a compelling research direction since there is a lack of framework that relates the collaborative learning techniques and the domains. Researchers can conduct empirical studies and find out the reasons why some domains are appropriate for collaborative learning while some are not. This distinction could be used to design a framework that would act as the reference point for a wider set of collaborative learning domains.

The utility of collaborative partners and the roles they assume could be analysed through empirical studies. The outcome of the studies could provide the basis for identifying the peers who would collaborate effectively, in a given domain, for a given learning strategy, and depending of the characteristics of the peers. From Table 2 it can be observed that the roles are dependent on the subject domain being addressed by the system. In general, analysis of roles for peers and the identification of a generic set of roles that are applicable for many of the collaborative domains would form interesting research topics in CSCL.

There is not much research on on-line assessment strategies to evaluate the need for a particular collaborative role, based on the student's interests. Thus, a representation scheme that supports collaborative interactions and models collaborating peers should be looked into.

Teaching multiple students in a collaborative system in a real-time networked environment, remains an underexplored field. Particularly, with the introduction of simulated peers, the task becomes more complicated. Controlling the interactions between simulated-peers and real-peers should also be an interesting research area.

Collaborative interfaces and collaborative communication languages have been dealt within recent research. Being a new field, CSCL requires innovative interface designs that maximize collaborative support for peers.

Like student modelling in ITS, collaborative student modelling is a promising research area in CSCL. Similarly, the collaborative tutor modelling and collaborative tutoring strategies are also potential research topics.

Diagnosis is one of the key issues in CSCL. There are situations where a peer would want to know the status of progress of other peers. In that case, the system is expected to diagnose the other peers' interactions and present concise and meaningful feedback. Applying such diagnosis as a filter to provide explanatory feedback would be an interesting research project. The explanations obtained could be customized depending on the user. For instance, the diagnosis could be explained with respect to a *marker* or a *teacher* or a *fellow student*. The same diagnostic output should be able to provide different explanations that suit different types of users.

The empirical evaluation of a collaborative learning system, is a research project in itself.

Collaboration is emerging as one of the promising learning paradigms in intelligent tutoring systems. Despite the complexity involved in the design and development of collaborative learning systems, more research efforts should be spent to explore this paradigm to provide better learning environments.

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System	Control	Task	Theory	Environment Design	Roles	Domain
ODISSEUS	CSCL	Concept learning	Socio-cultural	Expert, System	Expert	NEOMYCIN knowledge base
LEAP	CSCL	Design	Socio-cultural	Peer, System	Peer	VLSI circuit-design
Sherlock	CSCL	Problem solving	Socio-cultural	Peer, System	Peer, Expert	Electronic troubleshooting
Memolab	CSCL	Problem solving	Socio-cultural	Peer, System	Peer, Tutor, Expert	Domain-independent dialogue acts
Bootnap	CSCL	Design	Shared cognition	Peer(s), System	not-defined	Domain-independent artifacts
PREP	CSCW	Design	Socio-constructivist	Peer(s)	not-applicable	Collaborative writing
ShrEdit	CSCW	Concept learning	Socio-constructivist	Peer(s)	Writer, Editor	Collaborative text editing
Integration Kid	CSCL	Problem solving	Socio-cultural	Tutor, Peer, Student	Expert, Critique	Integration
Reciprocal-Kid	CSCL	Problem solving	Socio-cultural	Tutor, 3 peers, Student	Planner, Executor, Critique	Lisp programming
Three's Company	CSCL	Problem solving	Situated cognition	Tutor, Peer, 2 Simulated-Companions	Expert	Lisp programming
People Power	CSCL	Problem solving	Socio-cultural	Co-learner, Peer, System	Peer	Simulated electoral system
Distributed West	CSCL	Problem solving	Socio-constructivist	Peer, Companion, System	Peer, Competitor	Competitive arithmetic learning
Quilt	CSCW	Design	Socio-constructivist	Peer(s)	co-author, Commentator, Reader	Co-authored document development
Rescue	CSCL	Problem solving	Shared cognition	Peer, Companion, System	Peer, Simulated-roles	Role playing game

Figure 2: Dimensions of some collaborative learning systems