Computer-Supported Collaborative Learning Issues for Research

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Abstract:

This paper characterizes collaborative learning systems and identifies some of the dimensions of collaborative learning research.

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) delivers a collaborative environment that deals with "learning". On the other hand, Computer-Supported Cooperative Work (CSCW) deals with workplace collaboration. Most systems that belong to CSCL and CSCW work mostly in a *passive* fashion, where the system that delivers the collaborative environment does not attempt to exercise active control of the collaborative interactions.

Collaborative Learning can be characterized based on a number of dimensions including the type of collaborative control, the type of collaborative tasks, the theory behind the type of collaboration, the context in which collaboration happens, the type of participants, the roles of the collaboration participants, the collaborative domain, and the type of tutoring the thrives in a collaborative environment.

Depending on the type of collaborative tasks to perform, CSCL could be employed to address *concept learning*, *problem solving*, or *designing*. *Concept learning* deals with a single goal while the other two deal with a goal in terms of sub-goals. The number of solutions in *problem solving* is finite and computationally easier to represent. In *designing,* the number of solutions is not computationally tractable.

The ``WHY" section consolidates the motivation behind computer-supported collaborative learning research. The section on ``SYSTEMS" identifies some of the collaborative learning systems and categorizes them along the dimensions identified earlier. This is followed by a ``RESEARCH" section that contains a research proposal 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 [Piaget1928,Piaget1932] pointed out, collaborative learning has a major role in constructive cognitive development. His theory is consistent with other popular learning theories [Vygotsky1978,Fox & Karen,Thomas & Funaro1990] 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.

In one-to-one computer-based tutoring, the system interacts with one student and attempts to personalize 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, mediated by the collaborative learning system. The interactions among the students can be monitored and controlled by the system.

Typically, collaborative learning systems concentrate on refining and integrating the learning process and the subject knowledge of the students with the help of the collaborating 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 such as Socratic learning, discovery learning, integrated learning, etc. For instance, a 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, students can discuss these strategies with a group of fellow students who can advise, motivate, criticize, compete, and direct towards better understanding of the subject matter.

There are a number of experimental studies and implemented systems available in the literature to emphasize the effectiveness of collaboration. An experiment on *Constructive Interaction* by Naomi Miyake [Miyake1986] 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 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., & Corkill1989] 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,Blaye1989] 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 & Baskin1988,Chan1991] 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 compelling need for the infusion of collaborative techniques in learning environments.

Collaborative Learning Systems and Dimensions

This section lists some of the CSCL systems and a short description of each, providing a base from which the paper can attempt to synthesize the dimensions of CSCL research.

- 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 [Wilkins1988].
- 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 rulebase [Mitchell, Keller, & Kedar-Cabelli1986].
- 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 & Lesgold1993].

- 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, & Schneider1994].
- 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 [Dillenbourg1995].
- 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 & Olson1992].
- 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 is 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 [Chan1991,Chan1993].
- 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 [Lin1993].
- 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, & McCalla1992]. The system also supports a tutor who gives advice and plays the final judge if conflicts between different agents arise [Chan1993].
- 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 & Self1992a].
- 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 [Chan1993].
- 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 & Kraut1988] .
- 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 [Chan1993].

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 address issues specific to collaborative learning.

Dimensions of Collaborative Learning

Collaborative learning research can be viewed from seven different dimensions: control of collaborative interactions, tasks of collaborative learning, theories of learning in collaboration, design of collaborative learning context, roles of the peers, domains of collaboration and finally, teaching/tutoring methodologies that inherently support collaboration.

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 analyzing and controlling collaboration or act just as a delivery vehicle for collaboration. Depending on the amount of control embedded within, collaborative learning systems can be classified as *active* or *passive* systems or anywhere in the range between active and passive.

Tasks of Collaborative Learning

In a given collaborative learning environment, the collaborators could be faced with different types of tasks to perform. This paper identifies three types of tasks that are commonly found in a collaborative learning environment.

1. collaborative concept-learning tasks
2. collaborative problem-solving tasks
3. 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, peers have a single goal and they attempt to collaborate towards that goal. For instance, systems like Rescue and PeoplePower have a single goal that is not explicitly split into subgoals. On the other hand, an analysis/synthesis-based task typically splits the given goal into sub-goals and 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 implies the expectation of a singular purpose and a seamless integration of the parts, as if the conceptual object is being produced by a single effort [Smith1994]. 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 [Smith1994].

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:

1. socio-constructivist theory
2. socio-cultural theory
3. shared cognition theory

These three belong to *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

This theory advocates that students master new approaches of learning through interacting with others [Doise1990]. This theory is an extension of Piaget's [Piaget1928,Piaget1932] 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 & Mugny1984,Blaye *et al.* 1990,Blaye1989,Durfee, Lesser., & Corkill1989,Gasser1991].

Socio-cultural theory

This 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 [Vygotsky1978]. 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 [Vygotsky1978].

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 meta-conceptions 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 & Self1992b] 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 meta-conceptions mature into learned concepts.

Shared cognition theory

This 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, & Duguid1988,Lave & Wenger1991]. 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 Context

The backbone of collaborative learning is the willingness of the peers to participate and collaborate in a constructive sense. This has been studied by a number of educational psychology researchers [Madden & Slavin1983,Slavin1978] who confirm that peers in collaborating classes felt that their collaborators wanted them to learn. Slavin [Slavin1990] reports studies that confirm the willingness of peers to make the collaborative learning efforts succeed and the improvement in social status of the collaborators 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 [Slavin1990] reports a study by Kuhn [Kuhn1972] 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 [Azmitia1988] 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 because of the characteristics of peers or the experimental setup.

Azmitia's view is further supported by Rogoff [Rogoff1990,Rogoff1991] 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.

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, similar to the Extreme Programming methodology in Software Engineering. 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, the learning theory adopted, and the capability of the system. The following list presents a variety of collaborative environment designs:

1. 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.
2. Two or more peers collaborating with each other using an active tutor that controls and directs collaborative interactions.
3. 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.
4. 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.
5. 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 & Ohlsson1994] and Kumar [Kumar1992] discuss the generation, utility and control of simulated peers in collaborative learning.

Collaborative learning research has not identified formalisms for ideal collaborating context designs for peers.

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] prescribe 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.* Ideally, the system should maintain a model of peers in each of these roles [McCalla1990].

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. The goals are the learning objectives for the student. A list of goals comprises 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 [Galliers1988,Galliers1989] 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 [Blandford1994] presents a list of actions for aconflict-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 [Dansereau1988] 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 summarizes 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 [Webb1985] who found that the peers who gained the most from collaborative learning were those who provided elaborated explanations to others.

Explanations reinforce learning. Baker [Baker1991] 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'Malley1987] also emphasizes the importance of the selection of roles for peers. She reports that constructive collaboration takes place only if 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[Miyake1986] shows that the complex understandings of the working of a tailoring machine is better understood when peers interacted collaboratively and attempted to understand the problem. O'Malley [O'Malley1987] reports that spontaneous division of work occurs in collaborative learning in the domain of UNIX C-shell command interpreter. Connah et al. [Connah, Shiels, & Wavish1988] believe that the cooperative behavior 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 mostly unstructured. 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, such as solving anagrams, since the processes involved are not easy to verbalize. 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 can be conjectured 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 & Tzoneva1988] 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, & McCalla1991] and [Nichols1994] 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 [Wenger1988]. The degree of situatedness depends on the environment that simulates the collaboration.
- Negotiated Learning - this methodology, the student and the system negotiate mutually acceptable learning goals [Moyse & Elsom-Cook1992,McCalla1990]. The student model is expected to keep track of goals of mutual knowledge.
- Discovery Learning - e student explores an environment specially crafted to encourage learning. Peers could take individual roles in discovering the environment.

Table 1 presents collaborative learning systems in six dimensions. The seventh dimension, *tutoring* is not included in the table. Out of the 14 tabulated systems, 11 are classified as CSCL systems and the rest as CSCW. Most 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 inherently providing the roles of *expert* or *tutor*. The roles of the CSCL systems are predominantly domain-dependent.

Table 1 : Classification of collaborative learning systems under six dimensions

System	Control	Task	Theory	Environment design	Roles	Domain
Odisseus	CSCL	Concept learning	Socio cultural	Expert system	Expert	NEOMYCIN knowledgebase
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 artefacts
Prep	CSCW	Design	Socio constructivist	Peer(s) system	Not applicable	Collaborative writing
ShrEdit	CSCW	Concept learning	Socio constructivist	Peer(s) system	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
Three's company	CSCL	Problem solving	Shared cognition	Tutor, peer, 2 simulated companions	Expert	Lisp
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	Coauthored document development
Rescue	CSCL	Problem solving	Shared cognition	Peer, companion, system	Peer, simulated roles	Role playing game

Collaborative Learning Research - Proposal and Opportunities

This paper proposes a methodology to design and implement a generic collaborative learning tool. 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:

1. pre-collaboration tasks
2. core research in collaborative learning

Pre-collaboration 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 learning in addition to bootstrapping the learning session.

The domain should be validated for collaboration. Some domains are suitable for collaboration and some or not. There should be a mechanism to automatically recognize the type of domains and the validity of collaboration.

Identifying peers and verifying their suitability for collaboration is an important pre-collaboration task. Peers should be available over the computer network. Their suitability for collaboration with respect to the characteristics of other peers and available resources should be verified as well. 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 and validated. For instance, if the network load is too high to support real-time collaboration, the system should be able to withdraw from real-time collaboration. Compatibility of the collaborating tools used by different peers should be verified before collaborative sessions commence.

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

Core Research

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 many of the core research areas of collaborative learning in terms of the fundamental techniques that are derived from these fields.

- **Interface**s for collaboration should support a language through which the collaborating peers interact. The language should be task specific and expressive enough to address 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 consider various 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 [Galliers1988,Galliers1989] use first order logic to represent collaboration factors such as *conflicts*.

- **Coordination of collaboration** is a major process in collaborative learning. For instance, management of the roles assigned to peers is an interesting research topic that addresses questions such as *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 with positive interactions from all collaborating 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 research findings related to collaborative learning, ``Computer Science'' presents a completely different view of research in collaborative learning. 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 focusing 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 using both the education and the computer science perspectives.

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 analyzed through empirical studies. The outcome of the studies could provide the basis for identifying peers who would collaborate effectively, in a given domain, for a given learning strategy, and depending of the characteristics of the peers. From Table 1, 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 an interesting research endeavor.

Teaching multiple students in a collaborative system in a real-time networked environment remains an under-explored field. Particularly, with the introduction of simulated peers, the task becomes more complicated. Controlling the interactions between simulated-peers and real-peers should be a very 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 in CSCL.

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 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 huge research project in itself.

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

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