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# Mediating the mechanisms which make collaborative learning sometimes effective.

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## ABSTRACT

Computer-mediated communication (CMC) renewed the interest for collaborative learning. Empirical findings show that collaborative learning is efficient, but only under some conditions. These conditions are not guaranteed by the use of CMC tools. It would be an over-generalisation to expect any type of computer-supported collaborative learning (CSCL) to be efficient. It is also difficult to translate the conditions identified in face-to-face collaboration into conditions for success of distance collaboration, because too many other factors separate face-to-face from distance interactions. However, the analysis of these conditions reveals some mechanisms which explain the effects of collaborative learning. This contribution reviews the mechanisms which have been proposed and considers to which extent these mechanisms could be triggered in CSCL.

## 1. INTRODUCTION

This contribution concerns the use of Internet tools of interest to education. Let us briefly introduce two of these tools. The "World Wide Web" (WWW) [25] [26] is a distributed hypermedia system that runs over the Internet. In a hypertext, if you want more information about a particular subject mentioned, you can usually "just click on it" to read further details. WWW documents can be linked to other documents written by different authors, in various locations. To access the web, you run a browser program. The browser reads documents, and can fetch documents from other sources. Information providers set up hypermedia servers which browsers can get documents from. The browsers can, in addition, access files by FTP, NNTP (the Internet news protocol), gopher and an ever-increasing range of other methods. Finally, the browsers permit searches of documents and databases as well as "fill-out form" interfaces for accessing any kind of external programs running on a server. The WWW has great potential as a distance education tool. It delivers information to the learner in an easy way and allows for more sophisticated computer mediated communication tools such as dynamic hypertext, question/answer programs, conferencing systems, etc.

Multi-user Dimensions (MUDs) and its most powerful variant MOOs ("MUDs, object-oriented")[27], are becoming increasingly popular in the world of education, because many people can interact at once in some "virtual space". MUDs are sometimes called "text-based virtual realities". A MUD is partitioned into virtual spaces ("rooms") such that people and objects not directly with people or objects in a other room. All communication is text-based and interacts via TCP/IP sockets from client programs to a server machine. MOOs have a powerful internal programming language allowing to program sophisticated objets and actions that people can use. All MOOs contain internal communication and information systems. Some have interfaces to external Internet services (such as mail, gophers or www). Recently, prototypes of multi-media MOOs have appeared as well as WWW-MOO interfaces resulting in a similar functionality.

When one refers to 'distance education', the word 'distance' often sounds as the key word because it implies the use of salient technological tools. The spectacular feature of these tools may reactivate the belief that technological infrastructure per se enhances education. This belief influenced early research on computer-based learning when the question raised was "is computer-based learning more efficient than traditional classroom teaching?". It is clear nowadays that no effect can be expected from simply using a computer . The efficiency depends on the software features and on the educational activities built around this software. It may not be useless to say that this also apply to CMC. No technical infrastructure (networks, communication protocols) will guarantee the success of distance education. This success will depend on the developed software and the activities it supports. A scientific attitude implies to disentangle each CMC tool to find out which are its relevant features: Does it support synchronous or asynchronous communication, or both ? Does it mediate text, voice or images or any combination ? What is the 'cost' of interaction and of communication breakdown and repair ? Do the subjects in interaction exchange or share objects ? Does the technology enable to see what the other see (WYSIWIS), what the other does and where the other looks ? Does it support eye contact ? Does it enable anonymous participation ? ...

Although, these questions are not specific to Internet-based tools, there is one feature which is present in most of these tools: they are inherently distributed. This feature gives a boost to educational practices which were underdeveloped in educational technology. The main concern in computer-based learning was to support individualised instruction. Distance education technologies such as paper mail, television and video tapes have a bias towards straightforward teaching. CMC tools create the potential for decentralised forms of interaction. There is hence a renewed interest for collaborative learning. Can we transpose the results observed in face-to-face collaboration to distance settings ? This is the question we address here.

## 2. THE EFFECTIVENESS OF COLLABORATIVE LEARNING

There exists a large amount of empirical work on collaborative learning that has been conducted independently from any technology. This paper relies on the postulate that this body of knowledge may prevent us to repeat old mistakes with our new tools.

Scholars started with a simple question 'is collaborative learning more efficient than learning alone' ? While a majority of studies have shown that collaborative learning is often efficient [7], some studies brought contradictory evidence. Sometimes, collaborative learning does not work properly. The discrepancy between these findings led scholars to seek for conditions under which collaborative learning occurs to be efficient or not. A wide range of conditions or independent variables have been studied.

One factor that determines the efficiency of collaborative learning is the composition of the group. This factor is defined by several variables: the age and levels of participants, the size of the group, the difference between group members, etc. Regarding the number of members, small groups seems to function better than large groups in which some members tend be 'asleep' or excluded from interesting interactions [20, 21]. Most of the mechanisms which explain the effectiveness of collaboration (See next section), e.g. mutual regulation, social grounding, shared cognitive load, ..., can only occur between a few participants. This does imply that one has to reject any large group sessions, but that we learning activities should also include 'closed' sessions, in which a restricted number of subjects collaborate and/or 'monitored' session in which the teacher takes care that no learner is left out the interaction.

Regarding the participants, some developmental level is necessary to be able to collaborate, but this is only an issue for children and does hence not directly concern current distance education activities which mainly concern adult learners.

The most intensively studied variable is the heterogeneity of the group. It refers to the objective or the subjective differences (how subjects perceive each other) among group members. These differences can be general (age, intelligence, development, school performance, ...) or task specific. Results indicate there exists some 'optimal heterogeneity', i.e. some difference of viewpoints is required to trigger interactions, but within the boundaries of mutual interest and intelligibility. Heterogeneity can easily be understood as a condition to trigger conflicts and require social grounding, two important mechanisms described below. Heterogeneity is also implicit in the socio-cultural theory and its related mechanisms (see below) which rely on the observation of adult-child pairs or at least pairs with one member being more knowledgeable on the task than the other. Internet-based information and communication tools have a great potential with respect to heterogeneity: no infrastructure can better cross geographic, cultural and professional boundaries. Nevertheless, human beings have a natural trend to assemble with those who are the most similar to them. When participants join the group on their own decision, there is no control of heterogeneity. If the tutor observes too much homogeneity among the group members, he may modify some conditions in order to activate anyway the mechanisms that normally rely on heterogeneity. He may for instance allocate role to participants which will inevitably create conflict or provide them with contradictory information.

The effects of collaboration vary according to the task. For instance, some tasks are inherently distributed and lead group members to work on their own, independently from each other. Interaction occurs when assembling partial results, but not during each individual's reasoning process. Some tasks are so straightforward that they do not leave any opportunity for disagreement or misunderstanding. Some tasks do not involve any planning and hence create no need for mutual regulation. Some tasks cannot be shared, because they rely on processes (e.g. perception) which are not open to introspection or on skills (e.g. motor skills) that leave no time for interaction. If distance teachers want to take these features into account, a first attitude would be to use only collaborative learning for tasks for which it will get its optimal efficiency. Another solution is to modify the task, as explained in the previous paragraph, to make them more suited for collaboration. For instance, the 'jigsaw' method consists of providing group members with partial data. This method artificially turns a monolithic problem into a task which requires collaboration. Task features also include the environment in which the task has to be performed. This is especially important in computer-based tasks. The software features may modify interactions among learners. For instance, if a computer-based task provides the learner immediately with a feed-back on their actions, it may prevent them to discuss the consequences of their action

We might infer that the distance tutor should try to create the conditions that will optimise the probability that collaborative learning is efficient. The complexity of this task is however greater than it appears. Most of the variables (or conditions) presented above actually interact with each other. For instance, the effect of heterogeneity is not the same with different group sizes or with different tasks. The task effects may vary according to the communication media. It is difficult to really understand such second and third order interaction effects. Therefore, researchers have attempted to decompose the causal relationship between conditions and effects into two consecutive causal links: in some conditions, some types of interactions occur, and some types of interactions lead to learning effects [23]. For instance, explanations are more frequent when the group is moderately heterogeneous (high ability and medium ability students or medium ability and low ability students) and when the group is homogeneously composed of medium ability students [7]. The quality of explanations is lower for homogeneous high ability students (because they assume they all know how to solve the problem), homogeneous low ability groups (because nobody can help) and heterogeneous groups comprising high, medium and low ability (because medium ability students seem to be almost excluded from interactions).

Facing this complexity, the distance tutor cannot set up conditions which guarantee efficient collaborative learning. She should rather stop investigating collaborative learning at a general level and refer to more precise interaction processes which may or may not occur during collaboration. Hence a pessimistic conclusion would be that the only way to achieve partial control of learning effects is monitoring closely the interactions and check whether they offer a potential for at least some of the mechanisms that we have presented. Such a conclusion does not help much the designer. A more optimistic conclusion is to decide to look at the mechanisms by which collaboration is efficient, and to check whether these mechanisms can be - modus modendi - reproduced in computer-supported collaborative learning.

## 3. THE MECHANISMS OF COLLABORATIVE LEARNING

The fact that two learners can learn collaboratively is in some way a puzzle. From a 'learning as knowledge transmission' perspective, if two agents A and B both ignore some piece of knowledge, there is no reason why they could acquire this knowledge by simply collaborating. Since such learning actually occurs, scholars have suggested some mechanisms which account for knowledge acquisition through collaboration. Some of these mechanisms clearly relate to some psychological theory, mainly the socio-constructive and socio-cultural approaches. Other mechanisms belong, in a more 'neutral' way, to the recent work in cognitive psychology and cognitive science. The order in which we present these mechanisms does not reflect their importance in collaboration. These mechanisms are of course not independent, some of them may even correspond to the same cognitive processes, analysed from a different perspective.

### 3.1 Conflict or disagreement

The conflict between learners is, within the socio-constructivist theory [1], an extension of the Piagetian concept of conflict between the learner beliefs and his actions in the World. They postulate that when disagreement occurs between peers, social factors prevent learners to ignore conflict and force them to find out a solution. This theory is grounded in empirical work and sounds intuitively appealing. However, other empirical findings question this theory. On one hand, some diverging viewpoints among learners, which cannot be really described as conflicts, lead to learning gains [2]. On the other hand, when conflicts are not verbalized, they do not predict positive outcomes [3]. We can draw two conclusions from these findings. Firstly, a simple disagreement, a slight misunderstanding can be as efficient as a clear conflict between two agents who respectively believe P and not P. We come back in section 2.8 on the mechanisms used to build and maintain mutual understanding. The second is that verbal interactions generated to solve conflict are related to learning outcomes. This refers to the mechanism described in the section 3.4.

Those who experienced wide-area networked information and communication software know that they constitute of a rich ground for controversial discussions. This is especially the case for the "Usenet" newsgroups in which, besides technical or practical information exchange, one observes intensive debates. Those debates may not trigger appropriate mechanisms, because they are too philosophical, because there is a large turn-over in the participants or simply because the setting does not force them to reach agreement, even partially. Nevertheless, one can claim that such tools offer a great potential for conflictual interactions. One may ask whether the physical distance between participants, the rather anonymous participation of group members and the limited communication bandwidth (mainly text, no face to face communication) enable participants to engage into an intellectual debate with fewer emotional consequences than in co-presence interactions.

### 3.2 The alternative proposal

The second mechanism is close to the former. It is related to what psychologists refer to as the 'confirmation biases': subjects tend to design only experiments that confirm their hypotheses and to disregard any empirical finding that contradicts their hypotheses [4, 5]. The fact that the confirmation bias is reduced in collaborative learning can be explained by the 'conflict' mechanism: if the learners disagree, there are fewer chances that they design an experiment or a data analysis which satisfies one hypothesis to the detriment of the other. A complementary explanation is that the subjects are reluctant to abandon their own hypothesis because they do not have another hypothesis for replacement. The positive effect would then result from the fact that peers may propose an alternative hypothesis.

### 3.3 (Self-)explanation

When one pair member is more knowledgeable than the other, we understand easily than the latter learns from the former. What is more surprising is that the more able peer does also benefit from collaborative learning. It is now well documented that providing an explanation improves the knowledge of the explainer himself, even more sometimes than the explainee's knowledge. This effect is known in the cognitive science literature as the self-explanation effect. Chi et al [6] showed that asking students to explain aloud some physics examples (problems already solved), they proceduralize their declarative knowledge of physics, make explicit some implicit problem solving steps and thereby become later more efficient in solving similar problems. In the experiments, the explanations are rather artificially produced: the students are asked by the experimenter to do so. In collaborative learning, explanation occurs naturally or spontaneously. Similar effects have been observed in what we would call 'hetero-explanation' (by opposition to self-explanation).

However, Webb [7] observed that the cognitive benefits are restricted to elaborated explanations. Less sophisticated messages from the explainer do not produce effects. This confirms that the effect of explanation is related to the cognitive activity of building the explanation. We do not have knowledge of the cognitive effects of the other steps of hetero-explanation, mainly tailoring the explanation to the listener, and delivering the explanation. The current view is however not to consider the elaboration and delivery of explanation as two separate steps. Explanation is viewed as an interactive process in which two partners try to understand each other. These interactions influence the explanation generation from the very beginning. In some cases, one can say that explanation is built by the two partners (see section 2.8).

This dimension is important for the development of peer tutoring activities in distance education. Since the more able peer does also benefit from collaboration, it may be interesting to mix students from different levels, for instance from different academic years. Such activities can be credited to both students. This approach requires however that the problem to be solved by the partners keeps a certain complexity even for the more skilled peer. The interesting explanation is not the straightforward message. It involves some reflective activity from the explainer to articulate and integrate various pieces of knowledge.

3.4 Internalization

The previous mechanisms seem to indicate that conducting verbal interactions has an intrinsic learning effect. This position is central into the socio-cultural theory [8, 9]. In this theory, human cognition is shaped by the culture in general, and by the language in particular. When two people collaborate, they often have to justify their action to each other. The verbalisation of this knowledge seems to have an effect on both partners. The mechanisms of learning by participating into conversations has been called 'internalization' by Vygotsky [9]. The concepts conveyed by the interactions with more able peers are progressively integrated in the listener's knowledge structures. When integrated, they can be used in his own reasoning. Thinking is viewed a discussion that one has with oneself and which develops on the basis of discussions we had with others.

However, internalization only occurs if some conditions are met. One condition is that subjects can only assimilate concepts which are within their 'zone of proximal development', i.e. within the neighbourhood of the current cognitive level. Another condition is that the less able peer is not left as a passive listener, but participates into the joint problem solving strategy [10] . We come back on these question in sections 3 and 4.

3.5 Appropriation

Internalization is a rather vague and somewhat mysterious process. Some more concrete mechanisms have been identified. Appropriation is one of them. It results from to the opportunistic feature of collaboration. Let us consider two agents A and B such as B is more skilled on the task to be performed. When one agent A has performed some action, his or her partner B attempts to integrate A's action into his own plan, i.e. to appropriate A's action. Learning occurs when A reinterprets his actions with respect to how B appropriated it [11]. As Pea [28] stated: "Through interpretations by others, you may come to mean more than you thought you did" (p. 270). Agent A learns progressively how to assemble the elementary piece of actions that he is able to perform into a coherent problem strategy.

While the socio-cultural paid primary attention to adult-child interaction, the appropriation mechanism is interesting because it also concerns adult-adult interaction, the most frequent one the Internet. This mechanism is central to the apprenticeship method. This method focuses on how one learns from watching and working with a more skilled partner [12,13]. Another interesting aspect of this mechanism is that it also concerns non-verbal interactions, such as gestures in manual work or in sport, although this does not concern most distance education technologies.

2.6 Shared cognitive load

When two subjects collaborate, they often share the cognitive burden implied by the task. Spontaneously the group distributes the cognitive sub-tasks over individuals. We do not refer to the co-operative protocol in which the task is in advance split into sub-tasks that partners solve independently. This systematic division of labour does not correspond to our definition of collaboration, in which two or more subjects build synchronously and interactively a joint solution to some problem. However, it has been observed that some spontaneous distribution of roles occur in some collaborative tasks. Often, one subject performed the low-level operations while the other step back and monitors the activities oh his partner [14]. In computer-based tasks, the routine tasks are often played by the partner who holds the mouse. This distribution varies over time, the roles shift frequently, for instance, when one subject takes the mouse from his partner's hands [15]. This spontaneous process can be viewed at a higher scale as a economical principle: the group, as a system, tries to avoid redundancies. We come back on that point later. This division of labour enables each partner to devote more resources to the task allocated to him.

In terms of distance technology, the shared cognitive load implies a flexible turn taking. However, some scholars have set up efficient learning activities despite a rather rigid protocol. Brown and Palincsar [16] defined the 'reciprocal teaching method' and applied it to reading skills. One learner plays the 'teacher role' for a while, asking questions to the other in order to assess his understanding of the last sentences. For the next paragraph, the tutee becomes tutor and vice-versa. With this method, they obtained spectacular outcomes.

### 3.7 Mutual regulation

During collaborative problem solving, one often has to justify why we did something. These justifications make explicit the strategic knowledge that would otherwise remain implicit. Through these discussions, the two partners regulate mutually their partners activities. Blaye[2] observed that, after collaborative problem solving, partners perform better regulation skills individually. This mechanism can be viewed as a particular case of several of the mechanisms described above:

- With respect to the conflict mechanism, strategic decisions often raise argument, since heuristics often rely on non clear-cut or ill-formulated criteria ;

- With respect to the explanation mechanisms, the strategy underlying the solution path constitutes a point for which explanations are often requested;

- With respect to the internalization and appropriation mechanisms, it has been shown that the regulation of children activities by adults leads children to later use this metaknowledge [17] ;

- With respect to cognitive load sharing, one difficulty to perform metacognitive processes is that they enter into competition with lower cognitive process for resources (especially working memory). Metacognition involves an increased cognitive load. The fact of allocating cognitive and metacognitive processes (however artificial this boundary may be) to different agents benefits for the metacognitive layer (which often comes after other attention mechanisms).

Those mechanisms are nor exclusive, nor independent. They apply to various types of knowledge, but are especially relevant for the type of heuristic knowledge used for regulating problem solving behaviour.

Mutual regulation requires to each partner to monitor each other, i.e. to observe what the other is doing. We should here discriminate interfaces where one partner sees the results of the other's actions from interfaces where they see the actions themselves, for instance the cursor movements, the menu selections, and so forth. Another important interface feature is the extent to which the partners can see the trace of their activities, because regulation often implies an analysis of activities over a certain period of time.

### 3.8 Social grounding

Social grounding is the mechanism by which an individual attempts to maintain the belief that his partner has understood what he meant, at least to an extent which is sufficient to carry out the task at hand [19]. This mechanism involves that the speaker monitors the listener's understanding and, in case of misunderstanding, attempts to repair communication. Verbal and non-verbal cues are important to detect misunderstanding. Repairs involve disambiguating dialogues, pointing to shared souvenirs, to visible objects, drawing a schema, and so forth. Through this mechanism, both partners progressively build a shared understanding of the problem.

For Clark and Brennan [19] the cost of social grounding changes with the medium. They decompose this cost into eleven factors, among which two factors appear to us as especially relevant here:

- The speaker change costs.

  In face-to-face conversation, participants manage turn taking quite easily. There is an implicit rule that only one agent speaks at a time. When this rule is perturbed, for instance, when satellite-based communication introduces a one-second delay between the emission and the reception of a message, turn taking mechanisms are deteriorated. In Internet-based tools, one has to address those costs. Some tools for instance, require the partners to use some commands to inform that they take turn or that they end turn.

- Display costs

  Social grounding is easier when participants can monitor the facial expression of their partners, to find hints of misunderstanding or to know what they are looking at. When those facilities are not provided, it takes more efforts to detect and to repair misunderstanding. Note, for instance, that in text-based MOOs textually displayed "emotions" or "thinking aloud" fulfil this role.

These three last mechanisms illustrate a new theoretical perspective inherited from the situated cognition approach [19], and referred to as 'socially shared cognition'. This theory views a group as a single cognitive system distributed over individuals. It does not focus on individual contributions, but on the shared representation built by the group. Within this perspective, the main reason why collaborative learning is efficient is that members learn to think interactively: thinking is not only manipulating mental objects, but also interactions with others and with the environment [29].

## 4. Conclusions

Most of current widely available Internet-based tools use text-based communication, synchronous or asynchronous, with mostly fixed graphics and images. Voice and video interaction or voice and video mail are of course available, but the overload of standard networks and the limits of currently available hardware has postponed their larger use in current distance education. Most of the mechanisms described in the previous section can be conveyed via text-based communication, but with some perturbations. For instance, the cost of interaction being higher with text, the group members may reduce the number of disambiguating sub-dialogues used in social-grounding. At the opposite, in asynchronous text messages, they have more time to build sentences which are less ambiguous. Without video link, members also loose facial expressions which are useful to monitor the partner's understanding. Even with video images, they may see their partner but ignore where the partner looks, something which is important for understanding what she refers to. Some video system support eye contact appear to be related to metacognitive aspects [22].

In other words, we have no guarantee that the mechanisms described above will occur in computer-supported collaborative learning. But, there is no guarantee that they will occur in face-to-face collaborative learning either. However, what we wanted to stress in this contribution is that the benefits of collaborative learning are related to mechanisms which occur in what we refer to as a 'narrow' definition of collaborative learning. Some people use a much broader definition in which collaborative learning refers basically to a group of students following a same course. The group is usually larger (20 people instead of 2 or 3), the time scale is broader (an academic year instead of a few hours), and - more importantly - the activities of participants are weakly defined. They include any discussion among participants.

At the opposite, research on collaborative learning' actually focuses on 'learning through collaborative problem solving'. Most of the mechanisms we presented may only occur if two or more individuals are engaged into some activity which forces them to maintain some agreement and to reach eventually a shared solution. These results do not concern experiments in which subjects would roughly be left free to talk about whatever they want. Current discussions of Internet-based tools focus often on people sending messages, but neglect the reason why they communicate. The mechanisms we described in this paper concern goal-directed collaboration. In such settings, individuals are somewhat 'glued' into a single shared cognitive system by the fact that they are engaged into a convergent attempt to solve a problem. Therefore, more effort has to be spent on integrating collaboration features found in Computer Supported Cooperative Work (CSCW) tools into communication and information software available for "masses" on the Internet.

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