Dillenbourg P. (1999) What do yuo mean by collaborative leraning?. In P. Dillenbourg (Ed) *Collaborative-learning: Cognitive and Computational Approaches.* (pp.1-19). Oxford: Elsevier

Chapter 1 (Introduction)

What do you mean by 'collaborative learning'?

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1. Introduction

This book arises from a series of workshops on collaborative learning, that gathered together 20 scholars from the disciplines of psychology, education and computer science. The series was part of a research program entitled 'Learning in Humans and Machines' (LHM), launched by Peter Reimann and Hans Spada, and funded by the European Science Foundation. This program aimed to develop a multidisciplinary dialogue on learning, involving mainly scholars from cognitive psychology, educational science, and artificial intelligence (including machine learning). During the preparation of the program, Agnes Blaye, Claire O'Malley, Michael Baker and I developed a theme on collaborative learning. When the program officially began, 12 members were selected to work on this theme and formed the so-called 'task force 5'. I became the coordinator of the group. This group organised two workshops, in Sitges (Spain, 1994) and Aix-en-Provence (France, 1995). In 1996, the group was enriched with new members to reach its final size. Around 20 members met in the subsequent workshops, at Samoens (France, 1996), Houthalen (Belgium, 1996) and Mannheim (Germany, 1997). Several individuals joined the group for some time but have not written a chapter. I would nevertheless like to acknowledge their contributions to our activities: George Bilchev, Stevan Harnad, Calle Jansson and Claire O'Malley.

The reader will not be surprised to learn that our group did not agree on any definition of collaborative learning. We did not even try. There is such a wide variety of uses of this term inside each academic field, and *a fortiori*, across the fields. Moreover, the task force activities did not include a specific task which would have forced members to converge on a shared understanding of 'collaborative learning'. Instead, we shared a broad interest in multidisciplinary interactions, which was reified in this book.

Hence, I review the variety of approaches to 'collaborative learning' that were present in our group. When a word becomes fashionable - as it is the case with "collaboration" - it is often used abusively for more or less anything. The problem with such an over-general usage is two-fold. Firstly, it is nonsense to talk about the cognitive effects ('learning') of 'collaborative' situations if any situation can be labelled 'collaborative'. Secondly, it is difficult to articulate the contributions of various authors who use the same word very differently. Therefore, I explore various aspects of this definition, not in order to establish 'the' correct definition of collaborative learning, but in order to help the reader to put the different chapters in perspective. I will not review the chapters here, the reader might prefer to read them before reading this introduction.

The broadest (but unsatisfactory) definition of 'collaborative learning' is that it is a *situation* in which *two or more* people *learn* or attempt to learn something *together*. Each element of this definition can be interpreted in different ways:

- "two or more" may be interpreted as a pair, a small group (3-5 subjects), a class (20-30 subjects), a community (a few hundreds or thousands of people), a society (several thousands or millions of people)... and all intermediate levels.

- "learn something" may be interpreted as "follow a course", "study course material", "perform learning activities such as problem solving", "learn from lifelong work practice", ...

- "together" may be interpreted as different forms of interaction: face-to-face or computer-mediated, synchronous or not, frequent in time or not, whether it is a truly joint effort or whether the labour is divided in a systematic way.

These three elements of the definition define the space of what is encountered under the label 'collaborative learning': pairs learning through intensive synchronous joint problem solving during one or two hours, groups of students using electronic mail during a one-year course, communities of professionals developing a specific culture across generations, ... I explore this space along three dimensions: the scale of the collaborative situation (group size and time span), what is referred to as 'learning' and what is referred to as 'collaboration'.

2. The variety of scales

The different situations mentioned above create objects of study with different *scales* : from 2 to 30 subjects, from 20 minutes to one year. For instance, most empirical research on the effectiveness of collaborative learning was concerned with a small scale: of two to five subjects collaborating for one hour or so. At the opposite end of this scale, the label 'computer-supported collaborative learning' (CSCL) is often applied to situations in which a group of 40 subjects follows a course over one year. The findings of the former can of course not be generalised to predict the outcomes of the latter and vice-versa.

Generalisability is not only reduced by the difference in empirical settings, it has also been affected by divergent underlying theories. Just as a photographer uses different lenses for photographing a flower or a mountain, scholars need different theoretical tools in order to grasp phenomena on various scales. While psychology provides useful frameworks for analysing learning in small groups, social psychology applies better to broader groups, and tools from sociology, ethnology or anthropology become relevant for larger scales. Even within psychology, different schools of thought have focused on different scales, as Karen Littleton and Paivi Hakkinen explain in Chapter 2. These schools grew in geographically distinct places, namely Switzerland and Russia, at a time when distance and language were significant obstacles to scientific communication. They developed their own paradigms for empirical research which made the integration of results or concepts even more difficult. However, Chapter 2 demonstrates the continuity between these different schools of thought and articulates them with current approaches.

The notion of scale has been the 'Belin Wall' of collaborative learning: for many years, it has compartmentalised the field, but it fell in the late eighties: "... *research paradigms built on supposedly clear distinctions between what is social and what is cognitive will have an inherent weakness, because the causality of social and cognitive processes is, at the very least, circular and is perhaps even more complex*" (Perret-Clermont, Perret & Bell, 1991,p. 50). This evolution is illustrated by the emergence of distributed cognition theories (Salomon, 1993) in which the group is viewed as a cognitive system. Nevertheless, scholars study objects with different scales, but theoretical concepts are imported across different scales. For instance, Hutchins (1995) describes group processes with the terms that cognitive science used for describing individual cognition (memory, propagation of representational states, ...). Conversely, the notion of culture which implicitly refers to the level of community or society (even in adult-child interactions, the adult's role was mainly to be a mediator of culture of his or her society, not the creator of this culture) is now applied to describe the common grounds built by peers in interaction: "*The question is not how individuals become members in a larger cognitive community as they do in apprenticeship studies. Rather the question is how a cognitive community could emerge in the first place*" (Schwartz, 1995, p. 350). The process of building a group micro-culture is studied by Baker, Traum, Hansen and Joiner, in Chapter 3, and by Hansen, Lewis, Rugelj and Dirckinck-Holmeld, in Chapter 9.

During their transfer across different scales, these concepts undergo deformations. For instance, the notion of group memory has not been elaborated as much as the notion of individual memory. In

CSCL research, group memory is often reduced to a working memory, including a persistent representation of the problem state, mediated by some artefact (e.g. a shared visual workspace in groupware, an altitude meter in a cockpit, ...) and an interaction memory (e.g. the trace of last n interactions in a MOO environment). Conversely, if one talks about the culture built by two subjects after one hour of interaction, the term 'culture' acquires a functional flavour (the subjects develop the language they need in order to solve a task) rather than its traditional historical flavour. This functional flavour can be perceived in chapter 3 which describes the grounding mechanisms, i.e. the mechanisms for co-constructing a common language. These mechanisms are subordinated to a functional criterion: two partners can not gain perfect mutual understanding about everything in life, they simply need to have enough mutual understanding so that they are able to continue performing the task at hand (Clark & Brennan, 1991).

While distributed cognition treats the group as a single cognitive system, one may reciprocally view the individual as a distributed system (Minsky, 1987). This perspective broadens the scale issue, now including groups inside a single agent. Although it may sound awkward to talk about 'collaboration with oneself', it common to talk about 'conflict with oneself'. The idea that thinking can be viewed as a dialogue with oneself is not a new idea, it has been argued by Piaget, Mead and of course Vygostky, for whom thought results from internalised dialogues. The relation between dialogue with oneself and dialogue with a peer is addressed by two chapters.

- In chapter 6, Ploetzner, Dillenbourg, Preier and Traum compare explaining to oneself and explaining to somebody else. Learning by explaining to oneself received a great attention in cognitive science, both in machine learning under the label 'explanation-based learning' (Mitchell, Keller & Kedar-Cabelli, 1986) and in cognitive modelling under the label 'the self-explanation effect' (Vanlehn, Jones & Chi, 1992). In both models, explaining consists of building some proof in the AI sense, i.e. to 'understand' computationally. On the other hand, empirical research has established the cognitive effects of both (elaborated) self-explanations (Chi, Bassok, Lewis, Reimann & Glaser, 1989) and (elaborated) explanations (Webb, 1989, 1991). Does this imply that one can consider self-explanation and explanation as similar processes? Reviewing literature on this issue, Chapter 6 authors did not find any evidence that the interactivity of real explanation brings any benefit compared to self-explanation.

- In chapter 7, Mephu-Nguifo, Dillenbourg and Baker address this issue at the computational level, by comparing the operators used to model the co-construction of knowledge through dialogue and those used in machine-learning research to model individual learning.. Both sets of operators are rather similar at the knowledge level: for instance 'generalisation' can describe both the relation between two knowledge states during learning or the relationship between the semantic contents of two utterances in dialogue. However, this similarity does not extend to the strategy level: for instance, a dialogue strategy operator may be something like 'lying to check one's partner's agreement', while a learning operators would be 'focus on near-miss counter-examples'.

These two chapters apparently overturn my expectations: in the comparison between dialogue with oneself and dialogue with a peer, the main difficulty might not be to identify similarities, but instead to establish what exactly differs between the two processes. Investigating when and how individual reasoning takes the form of a monologue could contribute to understand the cognitive benefits of collaborative learning.

This evolution of research, where a group can be viewed as a unit or the individual as a group, indicates that the very notion of 'scale' actually changes: it moves from a property of the object to a property of the observer, who selects the most appropriate unit of analysis. In computational models, the choice is rather open since there is no 'natural' notion of agent as there is in psychology. A so-called 'agent' can be any functional unit inside the system: an 'edge detector' agent, an ANOVA agent, a grammatical parser agent,... Sometimes, a single rule is labelled as an agent, sometimes it corresponds to an entire rulebase. One finds the same variety of 'scales' in multi-agent systems as in psychology. Some systems include a few agents with elaborated skills while other include a large number of agents with elementary skills. The former perform meaningful computation, have goals, knowledge and even mutual representation. The latter are not viewed as intelligent agents, their interactions are not planned, but interesting phenomena hopefully emerge after a large number of interaction cycles. Sub-symbolic computation is often used in the latter. In Chapter 4, Weiss and Dillenbourg describe some mechanisms of learning in multi-agent systems. Actually, in the term 'multi-agent', we mainly discuss the prefix 'multi', i.e. what is really specific to multiple agents in comparison with single agent systems. I do not enter into the long debate in distributed artificial intelligence (hereafter DAI) regarding what can be called an agent. Agentship can be treated as a design metaphor. What must be assessed is whether the expectations which inevitably arise from such an anthropomorphic metaphor lead designers to be more productive or to cope with unsolved problems.

This book is mainly about the 'small scale' end of this continuum, i.e. collaboration between two or a few human or artificial agents for a well-defined learning or problem solving task. This bias, initiated by the individual perspectives of most chapter authors, increased progressively through the series of workshops we hold together. We deliberately left out of our debate some of the social and institutional factors which appear in large groups such as leadership, the emergence of norms, and so forth. Chapters 3 to 7 focus on dyads and short learning periods. In chapter 8, Hoppe and Ploetzner describe a CSCL approach applicable to broader groups and curricula. However, the specificity of their approach is to identify sub-groups (peers) within the group, which would benefit from a collaborative interaction with respect to one curriculum item. The main criterion for matching learners is the complementarity of their skills or knowledge. They present a computational model of the complementarity between quantitative and qualitative knowledge in physics. In other words, their focus is still on the narrow scale (2-3 learners during one hour) within a large scale system. This also characterises the first empirical study reported by Lewis, Hansen, Dirckinck-Holmfeld and Rugelj in chapter 9: within a broader institutional context, they study the interaction between two nurses and a physician. The second study is more illustrative of the 'larger scale' end of the spectrum. The authors consider a larger group, with a less-defined task, over a longer period of time. Not surprisingly, more institutional issues are raised during these observations. Specifically, learning is not studied in an instructional setting, but as personal and group development in work practices. This reveals a variety of understandings of the word 'learning' in 'collaborative learning' or the variety of tasks which are studied in collaborative learning research. I address this issue in the next section.

3. The variety of meanings for "learning"

In the research literature on collaborative learning, there is a broad acceptance of what is put underneath the umbrella 'learning'.

- For some scholars, it includes more or less any collaborative activity within an educational context, such as studying course material or sharing course assignments. The term *'collaborative learners'* would then be more appropriate.

- In other studies, and in most chapters of this book, the activity is joint problem solving, and learning is expected to occur as a side-effect of problem solving, measured by the elicitation of new knowledge or by the improvement of problem solving performance. This understanding is also dominant in research on multi-agent learning (see chapter 4).

- Within some theories (see chapter 2), collaborative learning is addressed from a developmental perspective, as a biological and/or cultural process which occurs over years).

- This spectrum also includes learning from collaborative work, which refers to the lifelong acquisition of expertise within a professional community (see chapter 9).

In other words, the common denominator of all these learning situations is more the word 'collaborative' than the word 'learning'. Still, the variety of uses of the word "learning" reflect two distinct understandings of 'collaborative learning': is it a pedagogical method or a psychological process? The pedagogical sense is prescriptive: one asks two or more people to collaborate because it is *expected* that they will thereby learn efficiently. The psychological sense is descriptive: one observes that two or more people have learned and collaboration is viewed as the *mechanism* which *caused* learning. The confusion between the descriptive and prescriptive views lead to frequent overstatements regarding the effectiveness of collaborative learning. I will argue that collaborative learning is neither a mechanism, nor a method.

- Collaborative learning is not one single mechanism: if one talks about "learning from collaboration", one should also talk about "learning from being alone". Individual cognitive systems do not learn because they are individual, but because they perform some activities (reading, building, predicting, ...) which trigger some learning mechanisms (induction, deduction, compilation,...). Similarly, peers do not learn because they are two, but because they perform some activities which trigger specific learning mechanisms. This includes the activities/mechanisms performed individually, since individual cognition is not suppressed in peer interaction. But, in addition, the interaction among subjects generates extra activities (explanation, disagreement, mutual regulation, ...) which trigger extra cognitive mechanisms (knowledge elicitation, internalisation, reduced cognitive load, ...). The field of collaborative learning is precisely about these activities and mechanisms. These may occur more frequently in collaborative learning than in individual condition. However, on one hand, there is no guarantee that those mechanisms occur in any collaborative interactions . On the other hand, they do not occur *only* during collaboration. At some level of description - at least the neurone level-, the mechanisms potentially involved in collaborative learning are the same as those potentially involved in individual cognition.

- Collaborative learning is not a method because of the low predictability of specific types of interactions. Basically, collaborative learning takes the form of *instructions* to subjects (e.g. "You have to work together"), a physical *setting* (e.g. "Team mates work on the same table") and other institutional *constraints* (e.g. "Each group member will receive the mark given to the group project"). Hence, the 'collaborative' situation is a kind of *social contract*, either between the peers or between the peers and the teacher (then it is a didactic contract). This contract specifies conditions under which some types of interactions *may* occur, there is no guarantee they will occur. For instance, the 'collaboration' contract implicitly implies that both learner contribute to the solution, but this is often not the case. Conversely, reciprocal tutoring (Palincsar and Brown, 1984) could be called 'a method', because subjects follow a scenario in which they have to perform particular types of interaction at particular times.

In summary, the words 'collaborative learning' describe a *situation* in which particular forms of interaction among people are expected to occur, which would trigger learning mechanisms, but there is no guarantee that the expected interactions will actually occur. Hence, a general concern is to develop ways to increase the probability that some types of interaction occur. These ways can be classified in four categories, three of them are addressed in this book.

To set up initial conditions. A first way to increase the probability that some types of interaction occur is to carefully design the situation. The most frequent questions that teachers ask are: What is the optimal group size? Should I select group members with respect to some criteria or leave them making group by themselves? Boys and girls together? Is it better to have group members who have the same viewpoint or not, the same general level of development or not, the same amount of knowledge with respect to the task at hand or not? Is it better to put them face-to-face or side-by-side? If the interaction is mediated through the network, what are the main features of the groupware to be used? Which tasks are suited for collaborative processes or not? These questions have inspired a large body of empirical research on collaborative learning. However, beyond a few main results, it appeared that these conditions interact with each other in a complex way (Dillenbourg, Baker, Blaye & O'Malley, 1995), the group heterogeneity effect will for instance be different for different tasks. Because of these multiple interactions, it is very difficult to set up initial conditions which guarantee the effectiveness of collaborative learning.

To over-specify the 'collaboration' contract with a *scenario* based on *roles*. This approach tends to turn collaborative learning into a method. For instance, reciprocal teaching (see Chapter 6) defines a clear specification of roles. Several methods are based on setting up systematic differences among learners, either for triggering conflictual interactions, or else because complementarity of learners' knowledge requires rich interactions: (i) asking subjects to play a specific role in an argumentation, even if the expressed viewpoint is not their personal viewpoint at the outset; (ii) to give different visual viewpoints to subjects (Doise, Mugny & Perret-Clermont, 1979), (iii) to control data access in such a way that group members access to different data ('jigsaw' method). Hoppe and Ploetzner's approach (chapter 8) can be described as a cognitively-oriented Jigsaw, i.e. based on knowledge complementarity between qualitative and quantitative knowledge. This approach defines initial conditions (selecting peers), but it is expected to influence interactions continuously: by selecting problems which cannot be solved solely with one type of knowledge (according to their computational model), the software forces the learners to integrate their respective knowledge.

To scaffold productive interactions by encompassing interaction rules in the medium. The teacher may specify interaction rules for face to face collaboration, such as "Everybody in the group should give his or her opinion". In CSCL, interaction rules can be continuously reinforced by encompassing them in the design of the (computer-mediated communication) medium. For instance, various research projects concern 'semi-structured' interfaces, i.e. interfaces in which the users communicate with a set of pre-defined buttons. Buttons either form a complete utterance (e.g. "Do you agree?") or open a sentence (e.g. "I propose to....") to be completed with free text. Generally, these buttons characterise the pragmatic value of an utterance (rather than its semantic value) and are hence not-surprisingly related to speech acts theory. Interesting results emerged — for instance that peers focus more on the task and producing fewer off-task comments with semi-structured interfaces (Baker & Lund, 1996; Jermann & Schneider, 1997). However, the case study presented in chapter 3 shows that the interface constitutes a tool - semiotic and physical - that users have to appropriate and which affects their understanding of the task beyond the simple facilitation/inhibition of particular types of interactions. How strongly or flexibly the interface should shape the interaction processes remains an open issue (Baker, 1997).

To monitor and regulate the interactions. The teacher thereby retains a role in the success of collaborative learning. This role is more important as the size of the group increases, and is hence not suprisingly emphasised in chapter 9 where large groups and less structured tasks are discussed. This role is often named 'facilitator' instead of 'tutor', because the point is not to provide the right answer or to say which group members is right, but to perform a minimal pedagogical intervention (e.g. provide some hint) in order to redirect the group work in a productive direction or to monitor which members are left out of the interaction. In the context of CSCL, the external regulator needs specific tools for monitoring the interactions occurring in different places and/or at different times. The design of this tool is a main item on the CSCL research agenda. The notion of multiple student models presented in chapter 8 constitutes a first step towards supporting teachers in managing group collaborative interactions. An alternative is to provide the peers themselves with tools for self-regulation of their interaction, for instance displaying the degree of asymmetry in action or the rate of acknowledgement in interaction (Dillenbourg, Traum, Jermann, Schneider & Buiu, 1997). We currently investigate whether peers are able to self-regulate their interaction with this type of feedback.

4. The variety of meanings for 'Collaboration'

So far, I have carefully avoided defining the word 'collaboration' itself. However, I am now obliged to address this issue. The adjective collaborative concerns four aspects of learning that have been mentioned in the previous section:

(1) A *situation* can be characterised as more or less collaborative (e.g. collaboration is more likely to occur between people with a similar status than between a boss and her employee, between a teacher and a pupil),

(2) The *interactions* which do take place between the group members can be more or less collaborative (e.g. negotiation has a stronger collaborative flavour than giving instructions)

(3) Some learning *mechanisms* are more intrinsically collaborative (e.g. grounding has a stronger collaborative flavor than induction), even if, at a very fine level of analysis, learning mechanisms must be similar to those triggered in individual learning (see section 3).

(4) The fourth element concerns the effects of collaborative learning, not because this element is used to define collaboration itself, but because the divergent views concerning how to measure the effects of collaborative learning participate in the terminological wilderness of this field.

In this section, I review the criteria applied to each of these four elements for justifying the term "collaborative".

4.1 Situations characterized as "collaborative"

Intuitively, a situation is termed 'collaborative' if peers are more or less at the same level, can perform the same actions, have a common goal and work together. I examine these four criteria. The two first concern the degree of symmetry in the interaction. One can discriminate various forms of symmetry:

- *Symmetry of action* is the extent to which the same range of actions is allowed to each agent (Dillenbourg & Baker , 1996),

- *Symmetry of knowledge* (or skills or development) is the extent to which agents possess the same level of knowledge (or skills or development). Actually, symmetry is often confused with heterogeneity: two learners may have a similar degree of expertise but different viewpoints of the task.

- *Symmetry of status* is the extent to which agents have a similar status with respect to their community (Ligorio, 1997).

- ...

Each type of symmetry can be objective or subjective (Krammer & van Merriënboer, 1989), interactions being for instance affected by the fact than one agents believes her partner to be more expert and hence adopts a weaker position in the argumentation. There is no situation of pure knowledge symmetry: There are no two individuals in the world with the same knowledge. Symmetry may change over time, for instance when partners address sub-tasks for which one peer has particular skills. Chapter 2 points out that the theories relevant to collaborative learning are based on empirical situations with different degrees of symmetry. Research in DAI uses the word collaboration for a variety of asymmetrical situations, for instance hierarchical multi-agent systems. A slight knowledge asymmetry among peers is generally considered as suitable, because it supposedly leads to conflicting interactions. However, despite this interest for knowledge asymmetry, situations depicted as collaborative are generally rather symmetrical, while other situational labels are used for highly asymmetrical situations with respect to actions (control, coordination, ...) or with respect to expertise (tutoring, teaching, coaching, ...).

The second criterion is that one generally expects collaborative agents to have *common goals*, whereas competition relies on conflicting goals. However, this criterion is not shared by all researchers, namely those working on sub-symbolic multi-agent systems. During the workshops with the chapters authors, I had the following debate.

> Let us assume a robot which moves randomly and drops randomly a piece of wood in a defined space. Another robot, which also moves randomly on the surface, hits the piece of wood and moves it further on. At the end of several thousands interaction cycles, it may occur that all pieces of wood dragged by all robots will converge towards a common place. This phenomena is depicted as if the robots collaboratively assembled the wooden pieces (Müller, 1995). Let us compare this with the case where I lose my car keys, somebody finds them and steals my car. Despite the fact that my distraction did indeed help somebody to steal my car, one would not say that we collaborated on the stealing of my car, because I had no intention of helping the thief to steal my car. We would only be viewed as collaborators - and both guilty - if I had deliberately given my key to get money from

> the insurance company. Similarly, those wood-transporting robots have no common goal (actually they even have no personal goal), they ignore that their action can create conditions for the actions of another agent. They would be collaborative if a robot computed where it should drop a piece of wood for enabling the transportation by the second robot. One robot simply changes the state of the environment, and this change affects the behavior of another robot.

If one transposes this notion of common goal from artificial agents to real people engaged in real life situations, one cannot simply assume that partners have completely shared goals, even if some external agent fixes this goal. This is clear for instance in the first case study in chapter 9, in which the two nurses and the physician, despite the obvious common goal of getting a new degree, have different expectations with respect to the joint project, because what they learn will affect differently the work practice in their own professional community. Shared goals can only be partially set up at the outset of collaboration, they have themselves to be negotiated (and probably revised as work progresses). Establishing common goals is part of constructing common grounds (chapter 3), since actions cannot be interpreted without refering to (shared) goals, and reciprocally, goal discrepancies are often revealed through disagreement on action. Through the negotiation of goals, agents do not only develop shared goals, but they also become *mutually aware of their shared goals*.

The third criterion concerns the degree of *division of labour* among group members. Collaboration and cooperation are sometimes used as synonymous terms, while other scholars use these terms distinctively according the degree of division of labour. In cooperation, partners split the work, solve sub-tasks individually and then assemble the partial results into the final output. In collaboration, partners do the work 'together'. However, some spontaneous division may occur even when two people do really work together, for instance one partner taking responsibility for the low levels aspects of the task while the other focuses on strategic aspects (Miyake, 1986). One could argue that the degree of the division of labour depends on the scale issue: at a high level of granularity, it should always be possible to find some division of labour between the partners. However, when one partner does the task-level and the other the meta-level, this leads to a *'horizontal'* division of labour into reasoning layers. This is quite different from the *vertical* division of work into independent sub-tasks as in cooperative situations. The difference is two-fold. Firstly, the layers have to be highly interwoven (one subject monitoring the other) while sub-tasks are independent. Secondly, the horizontal division of labour is unstable in collaboration (it is stable in coaching for instance), roles may shift every few minutes, with the regulator becoming the regulated, while cooperation refers to a more fixed division of labour generally made explicit at the outset. I continue this point in the next sub-section.

These three features (symmetry, shared goals and low division of labour) put chapter 6 into perspective. This chapter considers the cognitive benefits of building and delivering an explanation. However, the methodology used for observing systematically the effects of explaining generally involves experimental situations which are not symmetrical, where the peers do not have common goals and where labour is often systematically divided (explainer/explainee roles). These three differences lead me to think that the effects observed in truly collaborative situations might be very different from those reported in chapter 6, the results corresponding to a field of research which is still in its infancy.

4.2 Interactions characterised as "collaborative"

Another way to define collaboration is to say that it is a situation in which learners interact in a collaborative way. I hence review several criteria for defining collaborative interactions: interactivity, synchronicity and 'negotiability'.

A first and intuitive criterion is that a collaborative situation should be quite *interactive*. The degree of interactivity among peers is not defined by the frequency of interactions, but by the extent to which these interactions influence the peers' cognitive processes. The degree of interweaving between reasoning and interaction is difficult to define operationally. Hence, I illustrate it with a simple example. Let us assume that two architects must evaluate the value of two houses. If they cooperate, they will each evaluate one house. Their processes are independent: one might count space room by room, while the other uses the general dimensions of the house (as a cube). They will interact after a while in order to make their estimations consistent with each other; but these interactions come after the individual production of partial solutions, and hence will only influence them if these solutions have to be revised. If the two architects interact during the estimation process, one architect might say "Let's count from the basement", thereby leading his partner to measure space room by room instead of globally. This example is simple. At present, I consider producing operational criteria for defining the degree of interweaving between interaction and action to be a major challenge for collaborative learning research.

A second intuitive criterion is that 'doing something together' implies rather synchronous communication, while cooperation is often associated with asynchronous communication. If agent-A has for instance to regulate agent-B's reasoning, A and B must work synchronously and hence interact synchronously. This issue became salient in CSCW in which communication tools are often characterised as synchronous or not (see chapter 9). In fact, this dichotomy corresponds to the underlying technology but not to the real performance of communicative systems. For instance, while electronic mail is classified as asynchronous communication, chat box software is classified as synchronous. If a user in Geneva communicates with a colleague in London, the delivery delay might be 2 seconds in a chat box and 20 seconds by electronic mail. Where is the threshold beyond which one consider communication to be asynchronous? We controlled the delay of acknowledgement in a MOO environment, i.e. a text-based virtual reality including typed synchronous interaction (Dillenbourg & Traum, 1996). The average delay was 48 seconds i.e. longer than by e-mail. This long delay may partially due to lack of attention (the receiver is working on something else), but it includes the time necessary to produce the answer, i.e. to reason on it and to type it. Users of MOOs and other groupware systems have developed conversational rules for coping with this delay, to keep the floor, to initiate turn taking, and so forth (O'Conaill, Whittaker, & Wilbur, 1993). In other words, synchronicity is less a technical parameter than a social rule. Is it is a *considerate meta-communicative contract*: the speaker expects that the listener will wait for his message and will process the message as soon as it is delivered. If the medium breaks the conversational rules established for another medium, users create new ways of maintaining this *subjective feeling of synchronicity of reasoning*. In these same MOO experiments, we observed for instance that this synchronicity of reasoning often leads partners to make the same utterance simultaneously. One may hypothesise that the feeling of reasoning synchronously increases the process of mutual modelling, i.e. the effort produced by one agent to model the knowledge state of his partner.

Another feature of collaborative interactions is that they are *negotiable*. A main difference between collaborative interactions and an hierarchical situation is that one partner will not impose his view on the sole basis of his authority, but will - to some extent - argue for his standpoint, justify, negotiate, attempt to convince. Hence, the structure of collaborative dialogue is expected to be more complex than, for instance, tutoring dialogues. This point leads to several comments with respect to the chapters of this book.

- The degree of negotiability may be a difference between an explanation, as studied in formal experimental settings reviewed in Chapter 6, and the explanation which emerges from naturalistic collaborative situations.

- In addition to negotiating at the task level, collaborative partners have usually the possibility to negotiate how to interact (meta-communication), for instance in order to clarify the pragmatic value of an utterance (e.g. "Is that a question or a claim?') or to tune turn taking ('Let me speak'). Meta-communicative mechanisms have been identified in Chapter 7 as an important difference between the operators used by Michalski in machine learning and those by Baker in computational models of dialogue.

- Negotiation may only occur if there is *space for negotiation* (Dillenbourg & Baker, 1996), i.e. if something can actually be negotiated. Negotiation at the meta-communicative level can be inhibited by forcing partners to play well-defined roles (a growing trend in research on collaborative learning). Negotiation at the task level can be inhibited in trivial tasks, in which there is nothing to disagree upon, and in tasks with semantically obvious and unambiguous terminology, in which there is nothing to misunderstand. The boundary between misunderstanding and disagreement is shallow. I we do not understand each other, one cannot say to that we properly agreed. The grounding process is the bottom layer of the negotiation process (Dillenbourg & Traum, 1996). This grounding+negotiation process, i.e. the way through which partners can build a shared solution, hence became a central concern for research in collaborative learning. Chapter 3 is an ambitious attempt to relate a linguistic theory, developed by Clark and several colleagues, with the learning mechanisms described by the cultural-historical psychology. This chapter reflects a general trend: the growing contribution of linguistics — especially pragmatics — to theories of collaborative learning.

- The *space for misunderstanding* plays in grounding the same role as the space for negotiation in agreement. It constitutes an important element in modelling the dynamics of collaborative learning. Of course, any communicative act offers opportunities for misunderstanding. However, this space is for instance more narrow when partners negotiate the next action to be performed, or the meaning of an utterance (as in chapter 3) versus the situations in which they negotiate which problem they have to solve (as in chapter 9). Chapter 4 draws attention to the fact that the use of ambiguity-free (or noise-free) communication protocols in multi-agent systems, despite being understandably related with effectiveness matters, might be detrimental to the modelling of complex collaborative processes. Similarly, the linguistic model which underlies chapter 3 uses the concept of *least collaborative effort* to reach mutual understanding (Clark & Brennan, 1991), referring to the fact that the cost of producing an ambiguity-free utterance may be higher than the cost of collaboratively repairing the misunderstandings which may arise. The study of collaborative learning involves a different viewpoint: When two partners misunderstand, they have to build explanations, justify themselves, reformulate statements, and so on, all of these being activities which can lead to learning. Hence, in contrast with DAI and linguistic criteria, a collaborative learning situation should not eliminate (if possible) the probability of misunderstanding (in order to reduce the cost of communication), but instead leave the space for misunderstanding that is necessary for sustaining the subjects' efforts to overcome miscommunication. Of course, a too high level of misunderstanding would be detrimental to learning. We proposed the notion of *optimal collaborative effort* (Dillenbourg & Traum, 1996) to indicate that grounding efforts have to remain subordinated to the accomplishment of the task and the production of rich interactions.

4.3 Processes characterised as "collaborative"

In the previous discussion of synchronicity, I started by discussing synchronous interactions and moved to a discussion of synchronous reasoning and mutual modelling. In other words, the topic moved from defining collaborative interactions to defining mechanisms which are specific to collaborative learning. I explore this direction now. However, I said earlier that, at the most fundamental level, the learning mechanisms involved must be those that operate in the case of individual cognition, since there are still individuals agents involved in group interactions. In this section I review the mechanisms which have been studied with individuals and then extended to pairs and the mechanisms which seem to be more specific to collaborative learning. I start with mechanisms that are known to be central to individual cognition.

- *Induction*. Schwartz (1995) observed that pairs draw more abstract representations of the problem at hand, because their joint drawing had to integrate what was common to the representations built by each individual. The basic underlying process is inductive, i.e. to keep as relevant the features which are present in both representation. I would even argue that the grounding mechanism is inductive since the learner must induce patterns relating referring expressions with referents.

- *Cognitive load*. Another concept borrowed form individual cognition is that of cognitive load. In collaboration, the horizontal division of labour into, for instance, task-level and strategy-level tasks, reduces the amount of processing performed by each individual. Reduced cognitive load may explain why regulating one's partner processes is easier than self-regulation and therefore why groups members improve their regulatory skills (Blaye, 1988). Conversely, the interaction with other group members increases the cognitive load, which is not detrimental in itself (e.g. building an explanation is a cognitively demanding tasks, but still it leads to learning), but may become detrimental in case of over-load. For instance, Schnotz (1997) observed that while individuals perform better with animated pictures than with static pictures, pairs perform better with static pictures. He interprets this difference by the cumulative effect of the cognitive load involved in parsing dynamic pictures and the cognitive load due to social interaction. Chapter 4 investigates this point in the case of artificial agents. The balance between the reduction of individual computing due to division of labour and the increase of individual computing necessary for interaction (or central coordination) has been systematically investigated in DAI (Durfee, Lesser & Corkill, 1989; Gasser & Huhns, 1989). The cost/benefit ratio of splitting the work is a main criterion for comparing multi-agent architectures.

- *(Self-)explanation*. The case of explanation is different from the previous examples. The concept of explanation is, in itself, related to social situations, but it has been imported into studies of individual cognition, both in psychology (the 'self-explanation effect') and in artificial intelligence (explanation-based learning). The issue addressed in chapter 6 is whether the effects established with 'explanation for solo agents' can now be re-exported to collaborative settings, what needs to be added or removed to existing solo-models to fit with real (social) explanations.

- *Conflict*. The concept of conflict also concerns both the intra-individual and inter-individual planes. Although it is intrinsically a social concept, it was developped in cognitive science in the piagetian theory, i.e. individual-centred theory of development. Piaget's co-workers re-exported this concept to the case of social interactions, where a discrepancy between the knowledge or viewpoints of two peers leads to conflicting statements or positions with respect to the task at hand (Doise & Mugny, 1984).

The processes listed above are not specific to collaborative situations, they simply may occur more often or more spontaneously in those situations. Are there other learning processes would be very specific to social interactions?

- A short answer is the *internalisation* process, i.e. the "transfer" of tools from the social plane (interaction with others) to the inner plane (reasoning), since this process implies social interaction. Actually, this process has been more studied in asymmetrical situations (adult-child interaction being viewed in the Vygostkian approach as the 'motor' of development) rather than in collaborative settings as such (see chapter 2). Unfortunately, internalisation describes more an effect than its underlying mechanisms: one can observe for instance that some concept, is first introduced by an adult for solving the task with a child and then later on used by the child to reason about the task, but the successive steps which lead the child to 'think with' the concept are not clear. Wertsch (1985), however, gave some indications regarding the process itself. He showed that the main cognitive change was less the transition from the inter- to the intra-psychological plane, but, within the interpsychological phase, when the child becomes able to use the to-be-internalised concepts in his conversation with his mother.

- Chapter 3 authors might rephrase Wertsch's findings by saying that the concept has been grounded, i.e. became part of the common grounds built by the mother and her child. Another often quoted mechanism is *'appropriation'* (Rogoff, 1990) by which an agent reinterprets his own action or utterance under the light of what his partner does or says next (Fox, 1987). Again, the similitude with the grounding theory is striking. These similarities exist at two levels. At the interaction level, a rephrasing of what has already been said by one's partner would be viewed as repairing a misunderstanding in the grounding theory and as a re-formulating the previous utterance within a more elaborated conceptual framework for the socio-cultural theory. Chapter 3 investigates these similarities. At the cognitive level, both mechanisms assume that each partner maintains some representation of the other, that each partners infers from his partner's actions or utterances what he is thinking, what he believes, and so on.

- This 'model of the partner' may not be very detailed and accurate, not updated permanently, and will of course be of a lower quality as the number of group members increases or as the frequency of interaction decreases. It is certainly not complete, in the sense that it will be developed only up to the point where it needs to be developed to succeed in performing the task at hand (such as the grounding criterion which is also based on its functionality). Research on multi-agent learning also pays attention to this process (see chapter 4). Further research needs to be carried out in order to determine (i) how elaborated is the mutual representation that partners build; (ii) which processes are involved in mutual modeling; (iii) the extent to which these processes generate cognitive effects at the task / knowledge level. An hypothesis mentioned in chapter 7 is that *mutual modelling* implies some differential reasoning (comparing what I do or know to what my partner does or knows) and that the perception of discrepancies with respect to one's partner knowledge increases the awareness of one's own knowledge.

4.4 Effects of collaborative learning

Most research on collaborative has attempted to measure its effects, generally through some individual pre-test / post-test gain with respect to task performance. Some more specific effects have been described in terms of conceptual change (Amigues, 1987; Roschelle, 1992; Pea, 993) or increased self-regulation (Blaye, 1988; Gilly, 1989). The choice of these dependent variables leads to two methodological issues.

The first issue could be stated as follows: **'effects of what ?'**. As it appears from the above sections, a collaborative learning situation includes a variety of contexts and interactions. Talking about the effect of such a broadly defined term would be as meaningless as talking about the benefit of taking a medicine, without specifying which one. One should not talk about the effects of collaborative learning in general, but more specifically about the effects of particular categories of interactions (Dillenbourg et al, 1995). This implies controlling *a priori* which types of interactions will occur, as in some experiments on explanation reported in chapter 6, or analysing *a posteriori* which interactions did actually take place during collaboration - as in dialogue studies reported in chapter 3. The latter studies can be criticized for being too qualitative, leading to few conclusions, while the former can be attacked for their poor ecological validity. Both studies reflect however an important trend: researchers no longer treat (or should not) collaboration as a 'black box', but **zoom in** the collaborative interactions in order to gain better understanding of the underlying mechanisms. In this context, CSCL environments are a very interesting tools since they enable both a detailed recording of all interactions and careful design of the empirical situation.

The second methodological issue concerns the mode of evaluation. The effects of collaborative learning are often assessed by **individual task performance measures**. It has been objected that a more valid assessment would be to measure group performance. This 'validity' can be understood in practical terms: more and more professionals have to collaborate and it is an important goal for any educational institution to improve the students performance in collaborative situations. The validity issue has also a theoretical side: from the distributed cognition viewpoint, assessing groupwork through individual performance would be as meaningless as assessing a painter without his brush (Perkins, 1993). Within the group evaluation approach, one may verify whether the performance of a specific group has increased or assess if group members developed some generic ability to collaborate that they could reuse in other groups. The existence of this hypothetical ability to collaborate, although intuitively shared by many staff recruiters, remains however to be established, at least in cognitive science.

5. Theories of collaborative learning.

I have often used Roschelle's & Teasley's (1995) definition of collaboration, stated as follows: *"... a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem*" (p. 70). Compared to the four criteria listed in the previous section (situation, interactions, processes and effects), Roschelle's & Teasley's definition does not include the situation. A mutual effort of shared understanding does also occur in non-collaborative situations, for instance in teacher-pupil interactions (Douglas, 1991), and in virtually nearly all verbal interactions. However, this definition constrains the three other items. Shared understanding can be viewed as an effect, if the goal is really that a group builds the common grounds necessary to perform well together in the future. Shared understanding can be viewed as a process by which peers perform conceptual change. Shared understanding can be viewed as a condition for conducting effective verbal interactions.

A theory of collaborative learning concern these four items: criteria for defining the *situation* (symmetry, degree of division of labour), the *interactions* (e.g. symmetry, negotiability, ...), *processes* (grounding, mutual modeling) and *effects*. The main theories reviewed in chapter 2 (socio-cognitive, socio-cultural, ...) cover the four aspects, while more local theoretical contributions (e.g. the self-explanation effect) cover a specific aspect. The key for understanding collaborative learning is in the relations between those four items. At a first glance, the situation generates interactions patterns, these interactions trigger cognitive mechanisms which in turn generate cognitive effects. However, such a linear causality is a simplification. Most relations are reciprocal.

- There is a bi-directional link between the situation and the interactions: on one hand, the situation defines the conditions in which some interactions are likely to occur, but on the other hand, some situations are labelled 'collaborative' because the interactions which did occur between members were collaborative.

- There is a bi-directional link between the interactions and the processes, as illustrated above by the relationship between synchronicity and mutual modelling: I needed to refer to cognitive process (mutual modelling) in order to define a feature of interaction (synchronicity) beyond simple technical terms.

- There is a bi-directional link between the processes and the effects of collaborative learning. In principle, the processes generate the effects. However, some processes are described by the effects, such as 'internalisation'. Conversely, some effects are expressed in terms of group processes, such as the ability to work in group. This ambiguity is not specific to the field of collaborative learning: for instance induction can be viewed as a process by a psychologist while it might be viewed as the output of complex chemical processes by a neuro-physiologist.

- This ambiguity also concerns the distributed cognition theory, where the very idea of viewing the group as a unit can both be understood as a theoretical standpoint (group interactions being described as cognitive processes) or can be understood as the description of an effect or an achievement (some groups interact so well that they succeed in forming a distributed cognitive system).

6. Multidisplinarity in studies of collaborative learning

This book is intended to illustrate the benefits of collaboration between scientists from psychology and computer science, namely machine learning. Most chapters have been co-authored by scholars from both sides. The co-ordination of these views is especially important for chapters 4, 5 and 7. Two remarks must be made however. First, machine learning has not devoted a lot of attention to collaborative learning. The idea of collaborative problem solving has been explored in distributed artificial intelligence (DAI), where the focus was on immediate performance. It is only recently that more attention was paid to learning processes in multi-agent systems (Weiss, 1997). Moreover, it is not unfair to say that DAI has developed independently from the cognitive theories reported in chapter 2 and probably from linguistic theories. Chapter 4 describes some differences between multi-agent systems and cognitive psychology. Chapter 5 builds the comparison on a concrete case study, robots and humans having to perform the same task collaboratively. Chapter 7 compares the basic operators used to describe processes involved in machine learning and dialogue studies. In some way, these three chapters are rather modest in their scope and in their results. Their modesty has however to be compared to the width of the gap which separates cognitive psychology and DAI.

However, a few elements have helped to reduce the gap. First, this book focuses on cognitive psychology and hence deliberately neglected the socio-affective aspects of collaborative learning (it is also one of its weaknesses). This choice does not imply that social and affective aspects are not crucial to understand human-human collaboration, but that the cognitive layer is probably the easiest to start with when engaging a dialogue with computer scientists. Second, the dialogue was made easier by the fact the psychologists involved in this book all had a computer science experience, either because involved in computational models of cognition (e.g. chapters 6 and 8), either because they were involved in CCSL (chapters 3, 7, 8 and 9). CSCL is a very promising area for research not only because it answers to a strong social demand, but also because it enables scholars to 'zoom in' collaboration. By very carefully designing the situation, tuning up the interactions supported, by recording systematically all interactions, CSCL is the 'microscope' for scientists in this field. It also introduces a continuum between DAI and psychology, and an intermediate area where research is intrinsically multidisciplinary.

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