A method for evaluating computer-supported collaborative learning processes

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Abstract: Understanding and analyzing collaborative learning processes requires a fine-grained sequential analysis of the group interaction in the context of learning goals. Several researchers in the area of cooperative work take the quality of the group outcome as a success criterion. Nevertheless, recent findings are giving importance to the quality of the cooperation process itself. This paper presents a set of indicators the main objective of which is to evaluate the collaborative learning process. In this paper our aim is to present a method, which can be used in analyzing the interaction processes in a CSCL environment. We have defined an experiment to gather data from groups working on a simple task. These data are then used to build some cooperation indicators, which in turn allow us to estimate the quality of the work process.

Keywords: CSCL, CSCL process evaluation, indicators of collaboration.

Reference to this article should be made as follows: Collazos, C.A., Guerrero, L.A., Pino, J.A. and Ochoa, S.F. (2004) 'A method for evaluating computer-supported collaborative learning processes', *Int. J. of Computer Applications in Technology*, Vol. 19, Nos. 3/4, pp. 151–161.

1 INTRODUCTION

Probably the fastest growing area of research in the field of computer-aided education is that of Computer-Supported Collaborative Learning (CSCL). There are numerous available tools designed to support such a way of learning. Every tool promises similar benefits, whilst using the available technology in very different ways.

Dillenbourg *et al.* point out that for many years, theories of collaborative learning have been focused on how individuals work in groups, and recently, they have focused on the group itself, trying to establish when and under what circumstances collaborative learning is more effective than individual learning [1]. In this context, some independent variables have been identified and widely studied with respect to their effects on outcomes and on the process: the size and composition of the group, the nature and the objectives of the task, the media and channels of communication, the interaction between peers, the reward system and gender differences, among others [1–3]. Recent research, however, is giving emphasis to the study of collaboration *processes* and their support [4–5]. The work reported in this paper concerns the collaboration processes.

Collaborative learning is a complex phenomenon. Understanding group dynamics and the collaborative processes of decision making and learning in groups is important for both learners and instructors in collaborative learning programs. Understanding and analyzing the collaborative learning process requires a fine-grained sequential analysis of the group interaction in the context of learning goals. We may notice that supporting individual learning requires an understanding of the individual thought process, whereas supporting group learning requires an understanding of the collaborative learning process [6].

Collaborative learning research has paid close attention to studying pupils' interactions during peer-based work in order to analyze and identify the cognitive advantages of joint activity [7]. The computer provides opportunities to support and enhance some elements that could benefit the collaborative approach offering

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e.g., computer-based problem spaces for jointly creating and exploiting structures of common knowledge and shared reference [8]. A CSCL environment can provide structures and activities that foster monitoring of one's own and the other students' comprehension and reflect advancement of learning and problem-solving processes [9]. One way to do this is by using automatic data collection. The computer records the detailed actions that occur within the used program. The recording is often stored in log files that can be analyzed as part of the evaluation process. After the evaluation, the results can be shown in the CSCL environment as quantitative figures about the learning process.

Several researchers in the area of cooperative work take the quality of the group outcome as a success criteria. Traditional group work in solving problems tends to emphasize the product of the design and development process, but not the work process itself [10]. Nevertheless, recent findings are giving more importance to the quality of the *cooperation process* itself. Success in collaborative learning means both learning the subject matter (collaborating to learn), and learning how to effectively manage the interaction (learning to collaborate). The knowledge acquisition process for systems supporting collaborative learning warrants a closer look in light of this additional complexity [11].

The typical evaluation of collaborative learning has been made by tests taken by the students in order to determine *how much they have learned*. That is to say, a quantitative evaluation of the *quality of the outcome* is done. Some techniques of cooperative learning use this strategy (e.g. 'Student Team Learning' [12, 'Group Investigation' [13], 'Structural Approach' [14] and 'Learning Together' [15]). Nevertheless, little investigation has been done to evaluate *the quality of the collaboration process*.

Taking into account the characterization of cooperative learning presented by Johnson and Johnson [16], we further develop an Index of Collaboration proposed by Guerrero *et al.* [17], by defining a set of indicators.

These indicators are intended to help in the evaluation of the collaborative learning process. The model we propose is computer based. We have defined an experiment to gather data useful to build these cooperation indicators, which in turn allow us to estimate the quality of the work process.

This paper is organized as follows. In Section 2, we present some related work. Section 3 presents the Johnson and Johnson characterization of cooperative learning processes. In Section 4 we propose an evaluation instrument. Section 5 introduces the cooperation indicators as well as a method that allows us to evaluate some key points identified in the phases of collaborative learning. Section 6 describes the experimental design. An analysis of the results is done in Section 7, and finally, Section 8 presents some conclusions and proposals for future work.

2 RELATED WORK

The effects of CSCL cannot be measured along a single variable [18]; rather, a chain reaction occurs in which each event gives meaning to the next. This, says Salomon, is the reason why an appropriate methodology, as yet, has not been developed. As Ramage points out, 'the problems are partly to do with methodology and partly to do with goals — are we aiming to evaluate the usability of the systems, as in Human Computer Interaction, or do other factors become relevant?' [19]. He concludes by suggesting that new methods of evaluation need to be considered which will take account of individual, group and organizational effects as well as issues of usability. This opinion is probably most eloquently stated by Pea [20] who calls for the evolution of a new science, which embraces conversational and interactive analysis in interactive learning environments.

The answer seems to be to select a number of variables by which CSCL processes should be evaluated. Selecting these variables is a difficult task. Computer-based learning originates from a number of different academic backgrounds; most commonly Computing, Psychology and Education. Despite being inter-linked, problems may arise due to the different paradigms to which these disciplines belong [21]. Indeed, on the issue of which criteria should be adopted for the evaluation of CSCL, three distinct (but usually overlapping) schools of thought emerge: technical, social-psychological and cognitive.

Some sophisticated evaluation methods are developed by Fjuk [22] and Newman *et al.* [23]. Fjuk indicates the need for 'an analytical framework considering collaborative learning as a complex whole phenomenon of human actions'. Newman *et al.* want to incorporate the quality of learning itself which results from, but is an entirely separate issue from interactions with peers and tutors. This also seems to be the rationale behind Salomon's approach in which he eloquently describes the computer in collaborative learning as 'a Trojan Horse ... the proper use of which requires self-guided activities, team-work, and ongoing interdependence' [18].

Barros and Verdejo [4] have proposed an asynchronous newsgroup-style environment enabling students to have structured, computer-mediated discussions on-line. Evaluating the interaction involves analyzing the conversation to compute values for the four following attributes: initiative, creativity, elaboration, and conformity. Katz *et al.* [24] developed two rule learning systems: String Rule Learner and Grammar Learner. Using these systems people learn patterns of conversation acts from dialog segments that target particular pedagogical goals. Inaba and Okamoto [25] describe a model that draws upon the ideas of finite state machines and utility functions. They used a finite state machine to control the flow of conversation and to identify proposals, while applying utility functions to measure participants' beliefs with regard to the group conversation.

Muhlenbrock and Hoppe [26] developed a framework system for computer-supported cooperative learning and working. The system has been used in determining conflicts in focus setting as well as initiative shifts in aggregation and revision phases during some collaborative sessions on problem solving. Constantino-González *et al.* [27] developed a system that identifies learning opportunities based on studying differences among problem solutions and on tracking levels of participation.

Soller and Lesgold [6] have analyzed collaborative learning using hidden Markov's models. Additional work is needed to understand how students communicate and collaborate, and to apply this knowledge to develop computational methods for determining how best to support and assist the collaboration learning process. This is our rationale to propose a set of indicators in order to understand the collaborative learning process. Next there is an explanation of how we defined our set of indicators, based on the stages of cooperative learning processes presented by Johnson and Johnson [2].

3 STAGES OF COOPERATIVE LEARNING PROCESSES

A *cooperative learning process* is typically composed of tasks that must be carried out by the cognitive mediator or facilitator, and by the group of apprentices. In order to evaluate the cooperative learning process, we divide it into three phases according to its temporal execution: *pre-process*, *in-process* and *post-process*. Thus, *pre-process* tasks are mainly coordination and strategy definition activities and *post-process* tasks are mainly work evaluation activities. The group members will perform the tasks concerning the *in-process* phase, to a large extent. It is here where the interactions of *cooperative work processes* take place. Thus, our interest concentrates on the evaluation of this stage.

Table 1 summarizes the activities and specifies the corresponding phases. These activities define the structure of any cooperative learning activity that takes place in small groups, and in synchronous learning scenarios (face-to-face, same time, same place). We are interested in the evaluation of the activities that correspond to the *in-process* phase. Based on these, we will define some collaboration indicators. The next section introduces a software tool used to get raw data, which will be analyzed using the collaboration indicators.

4 TEAMQUEST

Since our goal is to study the collaborative learning process, we developed a tool to capture data from groups engaged in such work. We chose a case in which a small group of persons have to do some activities in order to do a joint task. The task is a labyrinth type game.

The game — called *TeamQuest* — is played by four persons, each one with a computer. The computers are physically distant and the only communication allowed is computer-mediated. All activities by participants are recorded for analysis and players are made aware of that.

Players are given very few details about the game. The participants while playing must discover most of the game rules. They also have to develop joint strategies to succeed.

4.1 System functionality

TeamQuest is a labyrinth with obstacles. The players in a team must reach a goal satisfying sub-goals in each of the game stages. Each player is identified with a role image and name. The main screen has three well-defined areas: game, communication and information (see Figure 1). The game area has four quadrants, each one assigned to a player who has the 'doer' role (active player), meanwhile the other players are collaborators for that quadrant. In a quadrant, the doer must move the cursor from the initial position to the 'cave' that

Table 1 *Activities of a cooperative learning process.*

Pre-process	*In-process*	*Post-process*
Design the contents	Application of strategies (positive interdependence of the goal, motivation between pairs, aid to learn)	Review success criteria
Specify the group size	Intra-group cooperation	Present the activity closure
Assign the groups	Review success criteria	Evaluate the quality of learning
Arrange the room	Monitor the activity	Self-evaluation of the group
Distribute the material	Provide help (from facilitator and from peers)	
Design the roles	Intervene in case of problems	
Specify the game rules	Feedback	
Define the success criteria		
Determine the desired behavior		

Figure 1 *TeamQuest game interface.*

allows to enter the next quadrant. In the way, the doer must circumvent all obstacles and traps in the map (which are not visible to all players). Moreover, the doer must pick an item useful to reach the final destination. The user interface has many elements showing awareness: the doer's icon, score bars, items which were picked up in each quadrant, among others (see Figure 1).

The communication zone has several windows with a face that characterizes each participant. To send messages each participant has an interface with a writing window, a receiver selector, and a send button. Also, there are three other windows, similar to the writing windows, which display the messages written by other players. On the other hand, the information zone shows information about the game status, obstacles, traps, individual views of the game, and the final game results.

Finally, the game score is computed based on the individual score of each player, shown in the score bars. These individual scores start with a predefined value and they are reduced or increased when a player collides with a trap or gets a reward (life potions). The group final score is the addition of the individual scores. Therefore, the common goal of this activity is to get the final position (the cave), with the highest possible score, by crossing the four quadrants, and getting from each quadrant the necessary items to carry out the mission.

4.2 Gathered information

The application has a structured chat-style user interface, through which the group conversation is held. The application records every message sent by any member of the group. Along with each message, it records the time of occurrence, sender, receiver and current quadrant (the mouse location — X and Y position — when the message was sent). In addition, it records the partial scores and total score by quadrant. The tool also registers the start and finish time of the game, the time spent in each quadrant, and the number of times each player looked at the partial and total scores by quadrant.

5 THE INDICATORS

Guerrero *et al.* [17] have defined an Index of Collaboration based on the structure of a cooperative learning activity explained in Section 3 above (in-process phase). That index was the simple average of five identified indicators based on some activities proposed by Johnson and Johnson [2].

In this work, we present a refinement of that Index of Collaboration, defining a set of indicators whose main objective is to evaluate the collaborative learning process. Four of the indicators are based on the following activities proposed by Johnson and Johnson

[2]: use of strategies, intra-group cooperation, reviewing the success criteria, and monitoring. The fifth indicator is based on the performance of the group. Each one of these indicators is explained in the next sections.

5.1 Indicator 1: Applying strategies

The first indicator tries to capture the ability of the group members to generate, communicate and consistently apply a strategy to jointly solve the problem. In the TeamQuest game, group members are forced to interact closely with peers since each player has a partial view of the game obstacles. If the group is able to solve the game, we can say their members have built a shared understanding of the problem (this is Dillenbourg's definition of *collaboration* [1]). They must have understood the underlying problem: the coordinator does not have all the information needed to move the mouse in her quadrant without hitting any obstacle, so she needs timely assistance from her collaborators. According to Fussell [28], discussion of the strategy to solve the problem helps the group members to construct a shared view or mental model of their goals and tasks required to be executed. This mental model can improve coordination, because each member knows how her task fits into the global team goals.

The learning potential of a team is maximized when all the players actively participate in the group discussions. Building involvement in group discussions increases the amount of information available to the group, enhancing group decision making and improving the students' quality of thought during the learning process [29].

In general, the specific measures to be considered for this indicator are subject-related. In our case study we decided that both the strategy the group applied and its success should be part of the indicator. Furthermore, we thought the strategy should have a weight four times larger than the one assigned to the success factor (whether or not the group solved the labyrinth). Thus, the applying strategies indicator (I1) should be built with 80% weight for the applied strategy and 20% weight for the success factor (solution). The strategy factor mentioned above was built from simple measures, which could be obtained from the raw data. The 80% weight was explained as 20% for whether or not the group was able to outline a strategy for the problem solution in an explicit way (use), 25% for using the defined strategy (maintain), 30% for negotiating, reaching consensus and disseminating information about strategy (communicate), and 5% for the quality of the strategy (quality). The quality measures included number of errors made by the group (related to the score) and number of mouse movements (related to efficiency).

5.2 Indicator 2: Intra-group cooperation

This indicator corresponds to the employment of collaborative strategies previously defined during the group work process. If each group member is able to understand how her task is related to the global team goals, then everyone can anticipate her actions, requiring less coordination effort. This indicator also includes measures related to the demands of every group member from their peers to reach the partial goal when acting as a coordinator.

A group achieves positive interdependence when the members of the group perceive that their goals are positively correlated such that an individual can only attain her goal if her team members also attain their goals [30]. In Collaborative Learning, these goals correspond to each member's need to understand her team members' ideas, questions, explanations, and problem solutions.

We have defined the I2 indicator (Intra-group cooperation) as: 80% employment of collaborative strategies and 20% providing help. Measuring the application of collaborative strategies implies the evaluation of coordination procedures and assessing the degree of joint understanding of the strategy. A good use of collaborative strategies should be observed as an efficient and fluid communication device among members of the group. Good communication, in turn, means few, precise and timely messages (1 — Work strategy messages/Work messages). Providing help may be measured by the number of supporting messages from peers when the coordinator requests them.

5.3 Indicator 3: Reviewing of the success criteria

This indicator measures the degree of involvement of the group members in reviewing boundaries, guidelines and roles during the group activity. It may include summarizing the outcome of the last task, assigning action items to members of the group, and noting times for expected completion of assignments. The beginning and ending of any group collaboration involves transition tasks such as assigning roles, requesting changes to an agenda, and locating missing meeting participants.

In the game, the success or failure of the group is related to the partial and global goals and hence, to the corresponding scores. In our experiment, the more concerned the player is with the goals of the team, the more checks to the scores she will do, and the more messages of this kind she will send. The indicator I3 (reviewing of success criteria) is then computed with a 0–1 range, where 1 means the highest score.

5.4 Indicator 4: Monitoring the activity

This indicator is understood as a regulatory activity. The objective of this indicator is to oversee if the group maintains the chosen strategies to solve the problem, keeping focused on the goals and the success criteria. If a player does not sustain the expected behavior, the group will not reach the common goal. In this sense, our fourth cooperation indicator (I4, monitoring the activity) will be related to the number of coordination messages, where a small number of messages means good coordination (1 — Coordination strategy messages/Coordination messages).

5.5 Indicator 5: Group performance

It refers to the quality of the proposed solution to the problematic situation. Baeza-Yates and Pino [31] made a proposal for the formal evaluation of collaborative work. They take into account three aspects: Quality (how good is the result of collaborative work), Time (total time elapsed while working) and Work (total amount of work done). So, in our experiment, Quality can be measured by three factors: errors made by the group (related to the best score), achievement of the main goal (the group can solve the labyrinth) and few movements of the mouse (related to efficiency). The tool records the play-time since the first event (movement of the mouse or message sent by any player), until the group reaches the goal (cheese) or loses the game (a partial score goes down to zero). In this view, the 'best' group does the work faster than the others. The work is measured through the number of messages sent by group members. The group performance indicator (I5), will be the average of the three aspects mentioned above (Quality, Work, Time).

6 EXPERIMENTAL DESIGN

The experiment has four phases. At the first phase, the group receives a brief description of the software tool. During the second phase, group members are assigned to network workstations, in separate rooms (synchronous distributed interaction). From then on, computers mediate all the communication. During the third phase, the group will try to solve the labyrinth. Finally, the fourth phase corresponds to the gathering and analysis of data recorded by the tool. We also conducted a final interview of the participants to foster a self-evaluation of the experience. This gave us a general overview of the problem perceived by each member of the team. So far, we have applied the experiment to 13 groups, as follows:

- A group of graduate students, from the course 'Collaborative Systems' at Pontificia Universidad Católica de Chile, with some experience in collaborative work techniques (group 0).
- A group of people, randomly selected, who had not met (group 3).
- A group of friends who have worked as a group many times before the experience and have a good personal relationship (group 4).
- Four groups of high school students from Cumbres de Santiago School, with an average age of 15 years old. Two of these were randomly selected (groups 1 and 2) and the remaining ones were friends (groups 5 and 6).
- Four groups of graduate students from Universidad de Chile (groups 7, 8, 9, 10).
- Two groups of undergraduate students from Universidad del Cauca (Colombia). One of these groups has worked as a group many times before the experience (groups 11 and 12).

7 RESULTS ANALYSIS

7.1 Applying strategies

The objective is not only to show which group got the best or worst score, but to analyze each one of the elements that are part of this indicator and so, determine why some groups are better than others. Table 2 shows the results.

From the collaborative work viewpoint, effective groups have goals which are clarified and modified as follows. There should be the best possible match between individual and group goals. They are also cooperatively structured so all members are committed to reach them. The results show us that groups are ineffective because communication is poor although they have high 'maintain strategy' scores. We can infer that members accept competitively structured imposed goals, so each member attempts to achieve her personal goal first.

We did not find that conflicts of interest were solved through integrative negotiation and agreement, that is to say there is not a mediated process. It was common to observe that the first coordinator tried to impose her viewpoint and the rest of the group members simply followed her instructions. The initial imperative messages typically were: 'Let's label the columns with letters and the rows with numbers', or 'I will move first and then you are going to send me your coordinates'. It was not frequent to find messages that could induce negotiation of a position, like: 'I propose that our strategy be ... do you agree?' or 'What do you think?' So, we can observe that the communication is not two-way and open with the possibility of expressing feelings

Table 2 *Applying strategies results.*

Group	*Solution*	*Use*	*Quality*	*Maintain*	*Communicate*	*I1*
0	1	1	0.62	0.62	0.36	0.69
1	0	0	0.5	0.68	0.41	0.51
2	1	1	0.95	0.65	0.26	0.68
3	0	1	0.52	0.59	0.36	0.68
4	1	1	0.87	0.64	0.37	0.71
5	1	1	0.74	0.74	0.43	***0.75***
6	1	1	0.56	0.71	0.35	0.71
7	1	0	0.5	0.60	0.32	0.47
8	0	0	0.4	0.61	0.35	*0.47*
9	0	0	0.4	0.65	0.35	0.48
10	1	0	0.5	0.62	0.34	0.48
11	1	1	0.87	0.71	0.41	0.74
12	0	1	0.5	0.65	0.34	0.68

as well as ideas. On the contrary, it was usually one-way, where only ideas were expressed and feelings were ignored.

The group that got the best score was group 5 (I1 = 0.75), so, we could think that it was a good group in this aspect (applying strategies). But if we analyze this indicator in detail, we can infer this was a good work group, but not a good collaborative group. Group 5 is ineffective as a collaborative group because the group could not build an effective communication method among members. This explains the 043 points obtained by this group in the *Communicate* aspect: it is the highest score, but is far from the optimal grade (1.0). In a collaborative activity, it is not only important to understand the problem, but to share that understanding among teammates, and this was Group 5's weakness. This group tried to promote discussion around the strategy definition; unfortunately, the final decision was imposed without a participatory negotiation.

It was common to find groups that did not obtain a high score even after defining a strategy for the first quadrant, with some members of the group understanding that strategy. The explanation lies in the lack of strategy understanding by *some* members of the group. We could observe, e.g., a group in which two of the members understood the strategy, and in fact partial results were very good during the first two quadrants. The problem appeared in the third quadrant, because the corresponding coordinator — who had not fully understood the strategy — began to make some movements according to her viewpoint, and obviously the group could not solve the labyrinth. In this case, the members who understood the strategy did not care to make sure the rest of the group did as well. Thus, it is not only important to understand the problem, but also to be sure that the rest of the people can understand the problem situation during a collaborative learning activity.

The team learning potential is maximized when all group members participate in the group discussions. Building involvement in group discussions increases the amount of information available to the group, enhancing group decision making and improving the participants' quality of thought during the learning process [29]. Consequently, encouraging active participation increases the likelihood that all group members understand the strategy, and decreases the chance that only a few participants understand it, leaving the others behind. Unfortunately, none of the observed groups behaved in this way and therefore, one wonders if this aspect of learning is not spontaneous, at least in a first session of collaborative learning.

7.2 Intra-group cooperation

This indicator provides information about the application of collaborative strategies defined in Section 6.2. Table 3 shows the results.

Table 3 *Intra-group cooperation results.*

Group	*I2*
Group 0	0.69
Group 1	0.71
Group 2	0.62
Group 3	*0.61*
Group 4	0.74
Group 5	**0.84**
Group 6	0.72
Group 7	0.80
Group 8	0.75
Group 9	0.75
Group 10	0.80
Group 11	0.80
Group 12	0.72

Concerning this indicator, we can note that almost all groups got a good score. These results show us there was an interest in solving the problematic situation among all members of the groups. It was common to observe that when someone asked for information about something, the other members of the group were able to resolve her doubts. Therefore, all questions — when asked — were solved by all group members.

It is possible to find a dialogue pattern by analyzing and observing the members' actions. When a participant requested help, at least she received one answer from the rest of the participants. It is important to note that these answers were timely. One of these patterns is shown below.

Coordinator: *Can I move to the right*?
Player 2: *I don't have obstacles.*
Player 3: *I don't have obstacles.*
Player 4: *There is an obstacle in that position.*

All the answers were given within a small time interval. Thus, the coordinator could infer what movement she could do and all participants were helping to solve the problematic situation.

Members of the group who are not influenced by positive interdependence engage in promotive interaction; they verbally promote each other's understanding through support, help and encouragement [32]. In the experiments, it was common to observe that if a member of the group did not understand the answer to a question or solution to a problem, her teammates made special reinforcements, sending messages like: 'Remember, you need to send me the location of your obstacles' or 'You cannot move', to address her misunderstanding before the group moved on. Ensuring that each member of the group receives the help she needs from her peers is key to promoting effective collaboration interaction. Thus, we can conclude all of our groups were good according to this indicator.

7.3 Success criteria review

This indicator gives information about the interest of members to check their roles, performance, and results in order to achieve the main goal. Table 4 shows the results.

This indicator provides an understanding of the performance analysis the group did during the group activity. Group processing and performance analysis exists when groups discuss their progress and decide which behavior must continue or change [32]. So, it is necessary that people evaluate the previous results in order to continue evaluating individual and group activities, and providing feedback. It is also necessary that members of the group take turns questioning, clarifying and rewarding their peers' comments to ensure their own understanding of the team interpretation of the problem and proposed solutions. 'In periods of successful collaborative activity, students' conversational turns build upon each other and the content contributes to the joint problem solving activity' [33]. Unfortunately, this did not happen with the analyzed groups.

If we look at the results, we could infer there were some groups who had a perfect performance on this indicator (groups 5 and 6). However, if we observe in detail the objective of this indicator, and observe the group logs, we can conclude that this aspect was not fulfilled as we would like. The results we got were relative scores, that is to say, the best groups were 5 and 6, but that does not mean they were good groups.

According to this indicator, it only reflects that we need to do additional experiments in order to determine the 'ideal group', and according to that group make relative comparisons. The groups with the best score were groups that reviewed the partial and total score during the process of collaborative activity, but were rarely or never interested in evaluating the results obtained in order to re-define the next movements, or to provide some feedback to the members of the group. It was unusual to find messages like: 'We are losing, our score is decreasing, so we need to define our next movement'. Only two groups (5, 6) had some messages like: 'Our score has increased', 'We are losing', but unfortunately, these groups did not stop to analyze their performance, to clarify issues and to define a new model of solving the problem situation.

7.4 Monitoring

This indicator gives an understanding of how the group maintains the chosen strategies to solve the problem. Table 5 presents the results. They show that members of the groups are interested in being consistent about the strategy, so there is a direct relation between this indicator and the aspect of maintenance within the Applying strategies indicator (e.g., the group that got the best I4 also got the best score in the maintenance part of CI1). Besides, it should be noted that the groups which scored best in this aspect were the ones having a history of working together for some time, so they had good internal relationships.

In cooperative learning groups, members are required to acquire group skills, like how to provide effective leadership, decision-making, trust-building, communication and conflict-management [32]. The combination of knowing how to manage intellectual disagreements and how to negotiate/mediate conflicts among participants' wants, needs, and goals ensures that the power of cooperative efforts will be maximized. The productivity of groups increases dramatically when members are skilled in how to manage conflicts constructively. Some groups participating in the experiment had worked together before, but still had the characteristics of 'work groups' and were not collaborative groups. The analysis of the messages shows that leadership was frequently delegated and based upon authority and, participation was unequal with high powered members dominating. These characteristics are typical of ineffective collaborative groups [34]. The same analysis gave us an understanding of the role of the coordinator in every quadrant. Her function should have been to contribute to maintain the harmony within group, avoiding negative discussions or conflicts, and promoting creative conflicts. Cooperation and conflict go hand-in-hand [16]. The more group members care about achieving the group goals, and the more they care about each other,

Table 4 *Success criteria review results.*

Group	*I3*
Group 0	0.2
Group 1	0.2
Group 2	0.2
Group 3	0.5
Group 4	0.8
Group 5	***1***
Group 6	***1***
Group 7	*0.2*
Group 8	*0.2*
Group 9	*0.2*
Group 10	*0.2*
Group 11	0.5
Group 12	0.5

Table 5 *Monitoring results.*

Group	*I4*
Group 0	0.75
Group 1	0.80
Group 2	0.80
Group 3	0.74
Group 4	0.78
Group 5	**0.86**
Group 6	0.85
Group 7	0.80
Group 8	0.82
Group 9	0.81
Group 10	0.83
Group 11	0.85
Group 12	0.81

the more likely they are to have conflicts with each other. The way conflict is managed largely determines how successful cooperative efforts tend to be. For this reason, we can conclude that our groups still functioned as work groups. They had not acquired the collaborative status yet.

7.5 Performance

Our last indicator provides an understanding of the fulfillment of the group. It provides an evaluation estimate of the groups' outcome, according to its definition in Section 6.5. Notice that the groups, which got the worst score, were the groups that almost got the best score for the other indicators (see Table 6). That observation provides a hint that the task performance of a group is not related to its collaborative skills.

At the end of the session a survey was applied in order to know the students's opinion about the collaborative activity. Some interesting comments were the following:

— 'The activity was great and I would like to repeat it'.
— 'Unfortunately, the game is over, I want to start again'.
— 'Although when I started the game I did not know how to proceed, during the activity I found its goal'.
— 'I had problems in interacting with my group'.
— 'Unfortunately, I never worked in a collaborative way, and I thought it was a competition'.
— 'Since I never worked collaboratively, I did not worry if my partners understood what I perceived or not'.

8 CONCLUSIONS AND FURTHER WORK

Understanding group dynamics and the collaborative process of decision making and learning in groups are interesting research fields. In the case of collaborative activities, performing well on a task implies not only having the skills to execute the task, but also collaborating well with teammates to do it.

Table 6 *Performance results.*

Group	*Quality*	*Time*	*Work*	*I5*
0	0.87	0.86	0.22	0.61
1	0.5	0.82	0.4	0.57
2	0.95	0.99	0.13	***0.69***
3	0.52	0.67	0.72	0.63
4	0.62	0.42	0.95	0.66
5	0.74	0.83	0.27	0.61
6	0.56	0.81	0.19	*0.52*
7	0.5	0.87	0.23	0.53
8	0.4	0.81	0.4	0.54
9	0.4	0.82	0.4	0.54
10	0.5	0.78	0.3	0.53
11	0.74	0.83	0.4	0.65
12	0.56	0.78	0.4	0.58

In this paper we have presented a software tool allowing us to evaluate cooperation processes occurring in group work. For their evaluation we proposed five cooperation indicators. We do not claim these are the only or best indicators that could be developed to this end. These indicators are not independent; e.g., there is a relationship between the monitoring indicator and the maintenance of the strategy, and another between intra-group cooperation and communication of the strategy. The important conclusion is that these five indicators did provide some insight into the collaborative work done by the groups. They can be used to detect group weaknesses in their collaborative learning processes.

The analysis of the results suggests that the shared construction of a strategy — understood and adopted by every member of the group — is related to a successful process, to the individual construction of cognitive context, and to the experiences shared by the group members. It also enhances the elaboration of strategies and facilitates its application. This fact is reflected in the performed language utterances: those are homogeneous, direct and unambiguous when referred to the common problem features.

The studied groups were ineffective collaborative groups because they were weak in collaborative attitudes. Students have two responsibilities in cooperative learning situations, according to Johnson and Johnson: 1) learn the assigned material, and 2) ensure that all members of the group learn the assigned material [35]. The second aspect is something that never occurred during the collaborative learning processes of our groups. Of course, nobody told the group members they should have a collaborative attitude. Many hypotheses can be developed to explain why these attitudes did not appear spontaneously: perhaps the students initially thought the game was very easy, or maybe they felt pressured to play instead of stopping to think carefully what to do, etc.

One could guess that a reduced number of work messages would imply a better coordination within the group and thus, one would find few coordination messages. This would occur because many messages would have an effect of cognitive overload, disturbances, etc. Our results support this relationship of number of work messages with number of coordination messages. However, again, well coordinated groups are not necessarily collaborative groups.

It is also important to note that the cooperative work processes are influenced by the personal style and individual behavior of every member of the group. We observed stability in the performance of the tasks accomplished by each of the group members, in both role types: coordinator and participant.

Further work is needed to study the influence of many variables we did not isolate in this experimentation. Such variables may be: gender (whether or not this factor has an effect on the results), age, culture, homogeneous *vs*. heterogeneous groups concerning the previous variables, etc. Other experiments could also be made changing the game. One of these changes may be allowing broadcast messages, or allowing the group to slightly modify the rules of the game (e.g., forcing the coordinator to receive all messages from members before enabling moves).

ACKNOWLEDGEMENTS

This work was supported by Fondecyt (Chile) grants No. 1000870 and 1030959; and graduate thesis scholarship No. 49 from Departamento de Postgrado y Postítulos, Universidad de Chile (2002), and by grant No. I-015-99/2 from Dirección de Investigación y Desarrollo (DID), Universidad de Chile.

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