

Evaluating Collaborative Learning Processes using System-based Measurement

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ABSTRACT

Much of the research on collaborative work focuses on the quality of the group outcome as a measure of success. There is less research on the collaboration process itself, but an understanding of the process should help to improve both the process and the outcomes of collaboration. Understanding and analyzing collaborative learning processes requires a fine-grained analysis of group interaction in the context of learning goals. Taking into account the relationships among tasks, products and collaboration this paper presents a set of measures designed to evaluate the collaborative learning process. We emphasise: direct system-based measures based on data produced by a collaborative learning system during the collaboration process, and suggest that these measures can be enhanced by also considering participants' perceptions of the process.

Keywords

Evaluating collaborative learning processes, CSCL, Collaboration processes, Group interaction

Introduction

Research on collaborative learning was concerned, initially, with the role of the individual in the group, then later with understanding the group itself, comparing the effectiveness of collaborative learning with individual learning (Dillenbourg et al., 1995). A number of independent variables have been identified and widely studied, including group size, group composition, the nature and the objectives of the task, the media and communication channels, the interaction between peers, the reward system and sex differences, among others (Adams et al. 1996; Dillenbourg et al., 1995; Slavin, 1991; Underwood et al., 1990). An alternative approach is to study collaboration *processes* (Barros et al., 1999, Brna et al., 1997). Indeed, it has been argued that understanding the process of collaboration is necessary to understand the value of collaborative learning (Muhlenbrock et al., 1999). The work reported in this paper concerns collaboration processes in computer-supported collaborative learning (CSCL).

Collaboration is “the mutual engagement of participants in a coordinated effort to solve a problem together” (Roschelle et al., 1991). Research on collaboration processes in CSCL is difficult because it is hard to measure collaboration for a number of reasons. These include:

- Collaborative learning technologies must go beyond generic groupware applications, and even the basic technology is not yet well developed (Stahl, 2002a).
- CSCL technology is difficult to assess because it must be used by groups, not individuals (Muhlenbrock, 1998).
- System-based measures of collaborative interactions tend to lose the collaborative content (Stahl, 2002b).
- Effective collaborative learning depends on subtle social factors and pedagogical structuring, not just simple tasks and technologies (Dillenbourg, 1999).

A number of different theoretical and methodological approaches have been taken to deal with these problems. Barros and Verdejo (Barros et al., 1999) analyzed students' online newsgroup conversations and computed values for initiative, creativity, elaboration and conformity. Inaba & Okamoto (Inaba et al., 1997) implemented a system that used a finite state machine to determine the level of coordination taking into account the flow of conversation of the group participants. Muhlenbrock and Hoppe (Muhlenbrock, 1999) developed a framework and system for determining conflicts in focus setting as well as initiative shifts in collaborative sessions on problem solving. Constantino-González et al. (Constantino-González et al., 2001) developed a system which identifies learning

opportunities based on studying differences among problem solutions and tracking levels of participation. An ICALTS Project identified indicators of students' interactions at the meta-cognitive level which might enable them to self-regulate or to assess their activity (ICALTS, 2004). Using activity theory as a theoretical framework, Barros et al. (Barros et al., 2001) developed a model to find "representational mechanisms for relating and integrating the collaborative learning elements present in real practical environments". Martínez et al. (Martínez et al., 2002) adopted a situated learning perspective. They defined a model that integrated group context and learning style. Soller & Lesgold (Soller et al., 1999) developed an approach to analyze collaborative learning using hidden Markov models, drawing on ethnomethodology (Garfinkel, 1967) and conversational analysis (Sacks, 1992). Drawing on the ideas in many of these earlier studies, Collazos et al. (Collazos et al., 2007) developed a mechanism which includes activities that provide the opportunity for students to examine a collaborative task from various perspectives so as to make choices and reflect on their learning both individually and socially. Their model is based on tracing all the activities performed during a collaborative activity similar to the affordances of video artifacts, through pauses, stops, and seeks in the video stream. Despite this wealth of studies, there has been a lack of attention to systematic evaluation of the quality of the collaboration process and definition of measures that might apply across different applications.

Several researchers emphasize the quality of the group outcome as a criterion for the success of collaborative learning. Typically, evaluation of collaborative learning has been made by means of examinations or tests to determine *how much students have learned*. That is to say, a quantitative evaluation of the *quality of the outcome* is made. Some techniques of collaborative learning use this strategy (e.g. "Student Team Learning" (Soller et al., 2000), "Group Investigation" (Sharan et al., 1990), "Structural Approach" (Kagan, 1990) and "Learning Together" (Johnson et al., 1975). This approach focuses on the intellectual product of the learning process rather than on the process itself (Linn et al., 1992). However, not all group learning is collaborative. It is common to find people in a group who have divisive conflicts and power struggles; or that a member sits quietly, and does not participate in the discussions; or that one member can do all the work, while the others talk about unrelated subjects; or maybe that a more talented member may come up with all the answers, dictate to the group, or work separately, ignoring other group members. While supporting individual learning requires an understanding of the individual thought process, supporting group learning requires an understanding of the process of collaborative learning (Soller et al., 1999). The designer of a collaborative learning activity needs therefore to design an activity that requires collaboration, i.e., so that the success of one person is bound up with the success of others (Collazos et al., 2001). This relationship is referred to as positive interdependence. Investigators have developed different ways to structure positive interdependence in software tools based on the interface design to ensure that students think "we" instead of "me" (Collazos et al., 2003a).

Because of the very complex interactions that occur in truly collaborative systems, where learning occurs through interaction among group members, understanding and analyzing the collaborative learning process requires analysis of group interaction in the context of learning goals. These goals may include both learning the subject matter ("collaborating to learn") and learning how to effectively manage the interaction ("learning to collaborate") (Soller et al., 2000). It is the second of these aspects of collaborative learning that is perhaps hardest to understand in detail. This is learning that is not merely accomplished interactionally, but is actually *constituted* of the interactions among participants (Suthers, 2005; Stahl, 2006). Therefore, whenever we are going to evaluate a CSCL system, it is not only important to try to evaluate the various mechanisms the software tool provides in order to help people learn through collaborative applications but to include some elements which allow evaluation of how people are doing a collaborative activity, taking into account their attitude towards collaboration. Following Garfinkel, Koschmann et al., (Koschmann et al., 2005) argue for the study of methods of building meaning: "how participants in [instructional] settings actually go about *doing* learning". In addition to understanding how the cognitive processes of participants are influenced by social interaction, we need to understand how learning events themselves take place during interactions among participants. Thus, we note that additional work is needed to understand the process of collaboration. This knowledge could be applied to develop computational methods for determining how to best support and assist the collaborative learning process (Collazos et al., 2003b). Our paper addresses this challenge.

We begin by breaking down the collaborative learning process into stages. This allows us to identify indicators that can be used to evaluate collaborative learning during that part of the process where students are learning through interaction. It also allows us to focus on what might be the outcomes of learning to collaborate during the process. We then describe some software tools we have developed to analyze interactions, and show how the indicators can

been used to evaluate the collaboration process for students using those tools. Finally, we discuss the benefits of the proposed approach, draw conclusions and identify opportunities for further work.

Stages of the collaborative learning process

Our interest is in designed collaborative learning processes, i.e. those processes that are designed by a facilitator in order to provide an environment for collaborative learning, rather than processes in which collaborative learning might occur spontaneously. Such a *collaborative learning process* is typically composed of several tasks that are developed by the cognitive mediator or facilitator and other tasks that are completed by the group of learners.

We divide the collaborative learning process into three phases according to its temporal execution: *pre-process*, *in-process* and *post-process*. *Pre-process* tasks are mainly coordination and strategy definition activities and *post-process* tasks are mainly work evaluation activities. Both the pre-process and post-process phases are typically accomplished entirely by the facilitator. On the other hand, the tasks accomplished during the *in-process* phase will be performed mainly by the learners (group members). This is where the interactions of the collaborative learning process take place. Our main goal is in evaluating this stage.

Drawing on Johnson & Johnson (Adams et al., 1996; Johnson et al., 1995), we can identify the tasks involved in the in-process stage of a collaborative learning process. Tasks completed by the learners are: application of strategies such as positive interdependence toward achievement of the goal, intra-group cooperation, reviewing success criteria for completion of the activity, monitoring, providing help and reporting. There are three facilitator tasks: providing help, intervention in case of problems and providing feedback.

Collaborative learning process indicators

Guerrero et al. (2000) developed an Index of Collaboration, measured as the simple average of scores on indicators that measured the learner tasks identified by Johnson & Johnson (Adams et al., 1996; Johnson et al., 1995). In this paper, we will develop a refinement of that Index of Collaboration. Four indicators will measure the following activities: use of strategies, intra-group cooperation, reviewing success criteria and monitoring. A fifth indicator is based on the performance of the group. All these indicators can be measured directly from data collected by the system as students participate in CSCL activities. In addition to these system-based measures of the collaborative learning process, we propose some additional measures of students' learning to collaborate based on participants' responses to the process.

Before we describe the indicators in detail, it is necessary to describe the collaborative environments from which metrics for estimation of the system-based indicators were gathered. In the next section, we therefore describe some software tools which we have developed to study the in-process stage of the collaborative learning process.

Software tools

We developed software tools to analyze the quality of the collaboration process for small groups working synchronously toward each of the two learning goals identified in the introduction to this paper: learning to collaborate and collaborating to learn. Four tools were used to study learning to collaborate and two tools were used to study collaborating to learn. Each of the tools is described in turn.

Chase the Cheese

For the first tool, we chose a small case in which a group of persons have to do some learning in order to complete a joint task. The task is a game of the labyrinth type.

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

Players are given very few details about the game. The majority of the game’s rules must be discovered by the participants while playing. They also have to develop joint strategies to succeed. In our studies, each person played the game only once.

Figure 1 shows the game interface. To the left, there are four quadrants. The goal of the game is to move the mouse (1) to its cheese (2). Each quadrant has a *coordinator* –one of the players– permitted to move the mouse with the arrows (4). The other participants –*collaborators*– can help the coordinator by sending messages which are seen at the right-hand side of the screen (10). Each player has two predefined roles: *coordinator* (only one per quadrant and randomly assigned) or *collaborator* (the three remaining players).

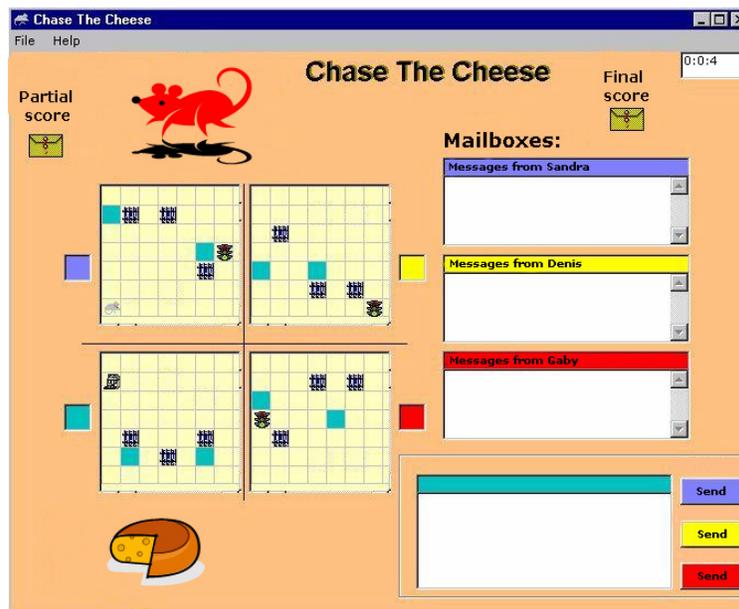


Figure 1. Chase-the-Cheese game interface

The game challenges the coordinator of a quadrant in which the mouse is located because there are *obstacles* to the mouse movements. Most of the obstacles are invisible to the quadrant coordinator, but visible to one of the other players. In each quadrant there are two types of obstacles through which the mouse cannot pass: general obstacles or grids (6) and colored obstacles (7). This is one of the features of the game which must be discovered by the players. The players must develop a shared strategy to communicate an obstacle’s location to the coordinator of the current quadrant. No message broadcasting is allowed, so players have to choose one receiver for each message they send (9). Since each participant has a partial view of the labyrinth, they must interact with their peers to solve the problem. In order to communicate with them, each player has a dialogue box (8) from which they can send messages to each of the others explicitly (one at a time) through a set of buttons associated with the color of the destination (9). For example, in Figure 1, a player can send messages to the other players with blue, red and green colors. Since each player is associated with a color, their quadrant shows the corresponding color (5).

When starting to move the mouse, the coordinator has an individual score (11) of 100 points. Whenever the mouse hits an obstacle, this score is decreased by 10 points. The coordinator has to lead the mouse to the cheese (in the case of the last quadrant) or to a traffic light (3), where the mouse passes to another quadrant and the player’s role is switched to collaborator while the coordinator’s role is assigned to the next player (clockwise). When this event occurs, the individual score is added to the total score of the group (12). Both scores, partial and total, are hidden. If players want to see them, they must pass the mouse over the corresponding icon displaying the score for two seconds. If any of the individual scores reaches a value below or equal to 0, the group loses the game. The ultimate goal of the game is to take the mouse to the cheese and do it with a high total score (the highest score is 400 points).

TeamQuest

TeamQuest is another labyrinth with obstacles, similar to Chase the Cheese but with some refinements (Collazos et al., 2004b). The screen has three well-defined areas: game, communication and information (Figure 2). The game area has four quadrants, each one assigned to a player who has the “doer” role; the other players are collaborators for that quadrant. Each player is identified with a role image and name which appear on the screen. In a quadrant, the doer must move an avatar from the initial position to the “cave” that allows them to enter the next quadrant. On the way, the doer must circumvent all obstacles and traps in the map (which are not visible to all players). In addition, the doer must pick an item useful to reach the final destination.

In TeamQuest, the user interface has many elements showing awareness: the doer’s icon, score bars, items which were picked up in each quadrant, etc. The need to collect objects on the way means the players of a team must reach a goal by satisfying sub goals in each of the game’s stages. In order to reach the final goal it is necessary to pass through every quadrant avoiding all the obstacles, i.e., if a person is not able to pass his/her quadrant, then it will be impossible to continue and thus the whole group will not reach the goal.

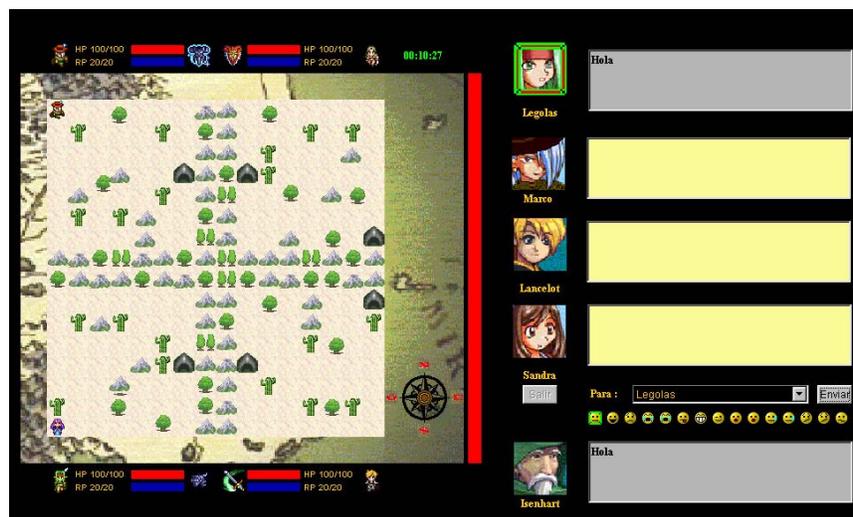


Figure 2. Team Quest User interface (in Spanish)

MemoNet

This game is loosely based on the classic “Memorize Game”, where the goal is to find an equal pair from several covered cards. This is repeated successively until there are no covered cards remaining. In the case of MemoNet, the idea is that four people try to find four equal cards from an initial set of ten different cards. The user interface is shown in Figure 3.

All players have the same set of cards but ordered in different ways. A person draws one card each time so they need to collaborate in order to solve the problem. A card is removed when all four players have found it. The game continues until all cards are uncovered and removed. The game is played in a distributed fashion, with communication allowed through a chat tool (Collazos et al., 2004a).

ColorWay

A fourth game designed to study learning to collaborate is *ColorWay*. This game has a 6 x 4 board of colored squares with obstacles (Figure 4). Players can see their own obstacles (with their own color). Each player has a token with his or her color, and this token can progress from the lower row to a target located on the upper row. The player can move the token using the arrows and back buttons only through gray squares which are not currently occupied by

another token. Other tokens further restrict movement: no token can go to row n if there is a token in row $n-2$. In a similar way to MemoNet, this game allows communication through chat. The problem is that there is only one way to arrange the tokens, therefore the players need to communicate in order to win the game (Collazos et al., 2004a).

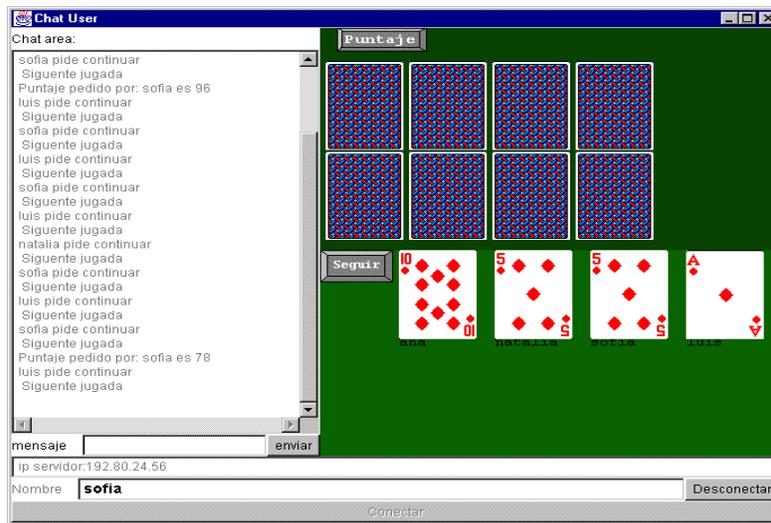


Figure 3. MemoNet user interface (in Spanish)

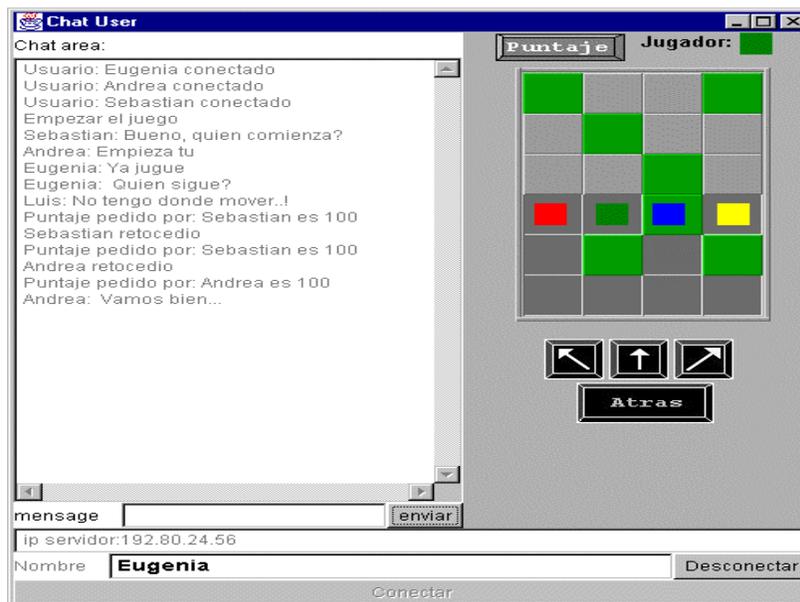


Figure 4. ColorWay user interface (in Spanish)

CCCuento

CCCuento helps a group to collaboratively write stories. Four participants work on four stories at the same time. Each story has four phases: introduction, body A, body B and conclusion. Each member must write a different section of every story. In a first stage every participant writes the introduction to one of the stories. In the second stage, every participant writes the first part of the development of a different story (body A) (Guerrero et al., 2003).

Then, they continue working until they finish all the stories. The group members may edit the parts they were responsible for at any time during the project (Figure 5).



Figure 5. CCCuento user interface (in Spanish)

DomoSim-TPC

DomoSim-TPC supports collaborative learning of domotical design (also known as house automation or intelligent building design) by students working at a distance (Redondo et al., 2006a; Bravo et al., 2006a). Domotical design aims at designing a set of elements that, installed, interconnected and automatically controlled at home, release the user from the routine of intervening in everyday actions. The aim is to provide optimized control over comfort, energy consumption, security and communications.) DomoSim-TPC supports a collaborative PBL (problem based learning) approach (Koschmann et al., 1996). Students are given a domotical design problem which they must solve by working collaboratively. Each student works at their own computer at a distance from the others.

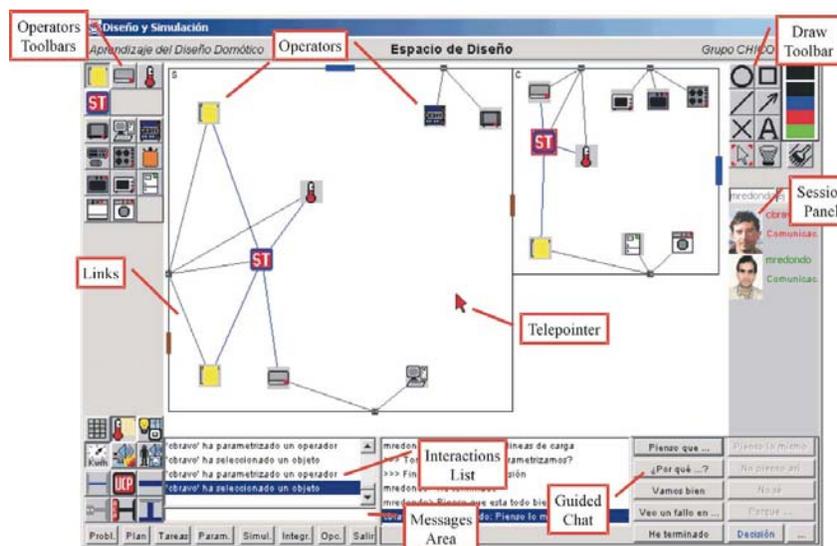


Figure 6. User interface of DomoSim-TPC design workspace (in Spanish)

The system is organized in different shared workspaces, each one for carrying out a specific task (planning, design or simulation). Figure 6 is a screenshot of the DomoSim-TPC design shared workspace (Bravo et al., 2006b). It contains tools for building models (designs), discussion and awareness. The work surface contains a house plan on which a set of operators has been inserted. On the left side of the window the domotical operator toolbars can be seen, and on the right is the drawing toolbar.

The discussion tool provides communication and coordination support. It consists of a Guided Chat and a Decision-Making tool. The awareness tool maintains a set of tele-pointers which show in which part of the model building area the users are working; a list of interactions which shows the actions taken by each user; and a panel containing the users' pictures, their names and their state (for example, editing, selecting, linking, simulating, designing, drawing, communicating). Each user has a unique color which is used to highlight their name and state and to identify their tele-pointer. In the central part of Figure 6, we can see the tele-pointer of the student collaborating with the student to whom the interface shown corresponds. As a user performs an action, it is shown immediately to the group members in the shared workspace. The action is recorded in the list of interactions and, optionally, the system will beep to capture the user's attention. All this allows users to know, for example, what the other students are doing, where they are, even what they may be likely to do next.

Measurement of indicators

As Jermann et al. (Jermann et al., 2001) note, measurement of system-based indicators begins with a data collection phase which involves observing and recording online interactions. Typically, users' interactions are logged and stored by the CSCL system. This raw data can be analyzed and summarized to provide simple interaction metrics. Indicators are higher level scores calculated from the metrics. In this section, we describe what raw data was gathered in our experiments and how it was aggregated into metrics and then indicators. We will conclude the section with some notes on measurement of additional user response variables.

Data collection

In order to analyze collaborative activity it is necessary to collect information about the collaboration process, recording information about the participants, actions performed, messages sent and received and time of each action. All the applications we developed include a mechanism to gather information. In *TeamQuest*, for example, we implemented 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, addressee and current quadrant (the mouse location –X and Y position) when the message was sent. Figure 7 shows an example of the information gathered by the application. In addition, the log 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.

X	Y	Quadrant	From	To	Message	Time
1	1	1	Andres1	Gaston	I need your coordinates	12:00:41 AM
			Andres1	Miguel	I need your coordinates	12:00:52 AM
			Andres1	Andres2	I need your coordinates	12:01:13 AM
			Andres2	Andres1	A2 y F4	12:01:25 AM
			Miguel	Andres1	A5 y G5	12:02:00 AM
			Gaton	Andres1	d3 y g3	12:02:08 AM
			Andres1	Gaston	your coordinates	12:03:13 AM
			Andres2	Andres1	ok	12:03:21 AM
1	2	1	Miguel	Andres1	Letters are arrows, columns numb	12:04:27 AM
						12:04:32 AM
1	3	1				12:04:37 AM
2	3	1				12:05:03 AM
2	4	1				12:05:52 AM
2	5	1				12:06:02 AM
3	5	1				12:06:07 AM
4	5	1				12:06:12 AM
			Gaston	Miguel	Well....	12:07:11 AM

Figure 7. TeamQuest interaction log

Metrics

In order to estimate each of the indicators, we first define some performance metrics. Metrics such as time, length of turn, and other countable events, are directly measurable and can often be automatically collected (Drury et al., 1999). The following table of metrics includes the observable data elements that were identified from our experiments as useful indicators of system and group performance. For each metric, we present its definition and some examples of ways to capture it in Table 1.

Table 1. Metrics

Metric	Meaning	Example
Number of Errors	Number of total errors performed during collaborative activity.	
Solution to the problem	The group is able to solve the problematic situation (Yes/No)	
Movements	Total number of mouse or pointer movements	
Queries	Total queries to the scores (Actions performed over the score icons)	
Explicit use of strategy	Outline a strategy for the problem solution in an explicit way (Yes/No).	
Maintain strategy	Use the defined strategy during all the activity.	
Communicate strategy	Negotiate, reaching consensus and disseminate information about strategy.	
Strategy messages	Total number of messages that propose guidelines to reach the group goal.	"Let's label the columns with letters and the rows with numbers"
Work strategy messages	Total number of messages that help the coordinator of the activity to make the most suitable decisions. These are typically sentences in the present tense that aim to inform the group about the current state of the group task.	"Stop, there is an obstacle in B3".
Coordination strategy messages	Total number of messages that correspond to activities whose main purpose is to regulate the dynamics of the process. These are typically characterized by prescribed future actions.	"I will move six squares to the right".
Work messages	Total number of messages received by the coordinator of the activity.	
Coordination messages	Total number of messages sent by the coordinator of the activity.	
Success criteria review messages	Total number of messages that review the boundaries, guidelines and roles of the group activity.	
Lateral messages	Total number of messages, such as social messages, that are not focused on the solution of the problem.	"Come on, hurry up, I'm hungry!!!!!!"
Total messages	Total number of messages received and sent by the group during the activity.	

The system-based process indicators

We identified five system-based indicators of the success of the collaborative learning process in section 3: use of strategies, intra-group cooperation, reviewing success criteria, monitoring and the performance of the group. Having introduced the metrics, we can now describe these indicators and how they can be estimated and applied.

Use of strategies

The first indicator tries to capture the ability of the group members to generate, communicate and consistently use a strategy to jointly solve the problem. According to Johnson & Johnson in (Adams et al., 1996), to use a strategy is

“to produce a single product or put in place an assessment system where rewards are based on individual scores and on the average for the group as a whole”.

In our collaborations, group members are forced to closely interact with peers since each player has only a partial view of the game (e.g., obstacles in the labyrinth games) or the solutions. Therefore, successful completion requires a strict positive interdependence of goals. If the group is able to complete the task, we can say its members have built a shared understanding of the problem (Dillenbourg et al., 1995). They must have understood the underlying problem. For example, in Chase the Cheese, the coordinator does not have all the information needed to move the mouse in their quadrant without hitting an obstacle, so they need timely assistance from their collaborators. According to Fussell (Fussell et al., 1998), discussion of the strategy to solve a problem helps group members to construct a shared view or mental model of their goals and the tasks that must be executed. This mental model can improve coordination because each member knows how their task fits into global team goals.

In DomoSim-TPC, this aspect is explicitly considered. The students solve the problems with the help of specialized tools. To successfully develop a design, they need to organize and distribute their work, drawing up a resolution strategy that divides the problem into sub-problems (Redondo et al., 2006b).

Measurement of use of strategies is related to the software environment in which it is used. In general, however, measurement should consider both the outcome of the collaboration and the nature of the strategy applied. In our experiments, outcome could be measured simply as success or failure in solving the problem. Strategy is more complex, and consists of elements of a) the quality of the technique or strategy actually used to solve the problem, b) explicit definition of a strategy, c) consistency or maintenance of the strategy throughout the collaboration, and d) communication of the strategy among group members.

Having identified the elements of strategy, we needed to consider how to measure and combine them. We sought a method that would be simple to understand and apply but powerful enough to distinguish between the performance of different groups. Measurement was based on the metrics introduced in Table 1. All elements were scored from 0 to 1. The most complex element to measure was the quality of the strategy used. This was measured as the mean movement, error and time to solution scores where each of these scores was a value from 0 to 1 based on the performance of each group relative to the performance of the worst group.

Using a data driven approach, we experimented with different weightings for each of the five components of strategy (solution of the problem, quality of strategy, explicit use of strategy, maintenance, and communication) with groups playing Chase the Cheese and Team Quest. We assigned the strategy elements a weight four times larger than the one assigned to solution of the problem. This weighting reflects the emphasis of our first indicator (C11) on the use of strategy; the outcome of use, although important, should not dominate the score. Thus, in calculating C11, the strategy applied had a weight of 80% and success had a weight of 20%. After experimentation, the 80% available for strategy applied included a small score (5%) to represent the actual strategy used. This weight reflects the fact that many different strategies can be used in practice to solve a given problem, but permits us to penalize groups that use an unusually large number of movements, have a large number of errors and/or use a large amount of time, even if they have other elements of strategy in place. The remaining 75 percentage points were allocated as 20% if the group explicitly outlined a strategy, 25% to the group's ability to maintain the chosen strategy throughout the process, and 30% for strategy communication.

This set of weights produced scores that could be used to compare groups meaningfully. For example, the group with the highest score in one test of Chase the Cheese scored 0.75 (out of a maximum of 1), with quite high scores (but not the highest) on all indicators except communication. Indeed, this group performed consistently and moderately well throughout the game, but with better negotiation and communication of strategy could have performed better. On the other hand, the group with the lowest score performed consistently, but moderately badly, throughout the game and did not reach a solution (Collazos et al., 2002).

Intra-group cooperation

This indicator corresponds to the application of collaborative strategies during the process of group work. If each group member is able to understand how their task is related to the team's global goals, then members can anticipate

actions. This requires less coordination effort. In the games, this indicator also includes measures related to the messages every player requires from their peers to reach their partial goal when acting as a coordinator. In DomoSim-TPC, group members need to communicate, exchanging information in relation to the domain, coordinating their actions and making decisions by coming to agreements in order to solve the problem (Bravo et al., 2006b).

A good application of collaborative strategies should be observed as efficient and fluid communication among members of the group. Good communication, in turn, means few, precise and timely messages. This component of the indicator was therefore measured as

$$CI2 = 1 - (\text{Work strategy messages} / \text{Work messages})$$

Providing help is represented by the number of supporting messages from peers. Technically, this measure may be computed as the ratio between the number of work messages and the total number of messages generated by the group.

Reviewing 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 dates or times for expected completion of assignments.

In TeamQuest, for example, the success or failure of the group is related to achievement of partial and global goals. It is shown in the obtained scores (partial and global scores). This indicator should also take into account the number of messages concerned with the reviewing mentioned above. It reflects interest in individual and collective performance. CI3 is then computed from the total number of messages that review the boundaries, guidelines and roles of the group activity. It is calculated as

$$CI3 = 1 - (\text{Reviewing messages} / \text{Total Messages})$$

Scores can range between 0 and 1, where 1 is the highest score. In DomoSim-TPC, e.g., this indicator is related to the correctness, validity and other characteristics of the design models built by groups of students. In this system, the relationship between success and strategies can be analyzed by studying the design plans and models that the students built.

Monitoring

This indicator measures regulatory activity. The objective is to measure the extent to which 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 collaboration indicator (CI4) is related to the number of coordination messages (i.e. messages in which the coordinator requests coordination information from collaborators) where fewer messages means good coordination. CI4 is calculated as

$$CI4 = 1 - (\text{Coordination strategy messages} / \text{Coordination messages})$$

Performance

Baeza-Yates and Pino (Baeza et al., 1997; Baeza et al., 2006) made a proposal for the formal evaluation of collaborative work taking into account three aspects: Quality (how good is the result of collaborative work), Time (total elapsed time while working) and Work (total amount of work done). In our experiments, Quality can be measured by three factors: errors made by the group, solution of the problem, and movements of the mouse. Work is measured by the number of messages sent by group members. In the games, the software records the play-time between the first event (movement of the mouse or message sent by any player) and when the group reaches the goal

(e.g., cheese) or loses the game (a partial score goes down to zero). In this view, the “best” group does the work faster. We scored each of Quality, Work, and Time on a scale of 0 to 1 where 0 is the worst possible performance and 1 is the best possible performance. The performance indicator, CI5, was measured as the mean score on these three aspects.

Summary of system-based indicators

The indicators are summarized in Table 2.

Table 2: Summary of Indicators

Indicator	Measurement					
CI1	Outcome		Strategy			
	Solution		Quality	Explicit use	Maintainance	Communication
	20%		5%	20%	25%	30%
CI2	1 - (Work Strategy Messages / Work messages)					
CI3	1 - (Reviewing messages / Total Messages)					
CI4	1 - (Coordination Strategy Messages / Coordination Messages)					
CI5	Quality		Time		Work	
	Few errors	Solution of the problem	Few movements	Total elapsed time while working	Total Messages	

We tested these indicators with 11 diverse groups playing Chase the Cheese (Collazos et al., 2002). Table 3 shows that the indicators allow us to identify groups that perform consistently well or badly, while providing enough discrimination to distinguish the strengths and weaknesses of collaboration in each of the groups.

Table 3: Result of use of Indicators in Chase the Cheese

Group	Strategy CI1	Cooperation CI2	Reviewing CI3	Monitoring CI4	Performance CI5
Group 0	0.69	0.69	0.2	0.75	0.65
Group 1	0.31	0.71	0.2	0.80	0.57
Group 2	0.68	0.62	0.2	0.80	0.69
Group 3	0.48	0.61	0.5	0.74	0.63
Group 4	0.71	0.74	0.8	0.78	0.66
Group 5	0.75	0.84	1	0.86	0.61
Group 6	0.71	0.72	1	0.85	0.52
Group 7	0.47	0.80	0.2	0.80	0.53
Group 8	0.27	0.75	0.2	0.82	0.54
Group 9	0.28	0.75	0.2	0.81	0.54
Group 10	0.48	0.80	0.2	0.83	0.53

Other indicators of learning to collaborate

We have defined a set of system-based indicators that will permit us to evaluate students’ learning to collaborate. Other indicators have been developed for specific projects, e.g., a method based on genetic algorithms to measure the relationship between process (level of collaboration) and product (correct solution) in activities carried out using DomoSim-TPC (Molina et al., 2006). All of these indicators rely on data generated by the CSCL system. They do not consider, however, the users’ perceptions and psychological responses to participation. We have therefore included in our evaluation aspects related with community psychology and social and educational psychology. We defined meta-response variables that represent the personal development of individuals which psychologists believe can result from effective participation in collaborative learning processes (Francescato et al., 2006). These variables include cognitive empowerment, self-efficacy as a learner, self-efficacy for computer use, attitudes to computer-

supported learning, and attitudes to collaborative work. Full detail of these measurements is provided in other works (Klobas et al., 2000; Klobas et al., 2002), but as an example, we discuss one of them, Attitudes to collaborative work, here.

To measure Attitudes to collaborative work, four items were adapted from the Grasha-Reichmann descriptions of the collaborative learning style (Hruska-Riechmann et al., 1982). Typical items were "I like to work with other students" and "Group work is a waste of time". They were measured on a 4-point scale with values of 0 (*Never*), 1 (*Rarely*), 2 (*Sometimes*), 3 (*Often*). Cronbach's alpha was satisfactory (above .7 in all administrations) and the scale was additive. Responses to the 4 items were summed to give an attitude to collaborative work rating on a scale of 0-12.

Discussion

Typically, evaluation of collaborative learning has relied on examinations or tests to determine how much students have learned, however, the model proposed in this paper is based on measuring collaborative learning processes. We have derived indicators of the quality of student work during the in-process phase of the collaborative learning process from a prominent model of collaborative learning (Adams et al., 1996) and shown how these indicators can be calculated from data recorded during the collaboration. Use of these indicators can provide insight into the collaboration process. Based on the results, evaluators can identify problematic situations and plan new strategies in order to improve collaborative learning.

System-based indicators can be used to monitor the learning process while a collaborative activity is proceeding. They may be used to alert an instructor to the need to intervene in the process. In such cases, it is necessary to design the collaboration so that the instructor knows how to intervene in order to improve the process (Katz, 1999). It is necessary for the teacher not only to monitor the activities of a particular student but also the activities of his peers to encourage some kind of interaction that could influence the individual learning and the development of collaborative skills, such as give and receive, help, and receive feedback and identify and solve conflicts and disagreements (Dillenbourg et al., 1995; Johnson et al., 1992; Webb et al., 1996). Interventions can be difficult to identify if they are managed in a manual way, especially when the teacher is working with several groups of students in the same class at the same time. Our model of evaluation allows the teacher to observe the interaction at an aggregated level and to be alerted to opportunities to intervene.

Monitoring can help a teacher to identify which aspects of the group process are more complicated. This is an extremely important aspect of any mechanism of evaluation because it provides the opportunity to determine how to improve the shortcomings of the group process that were detected from analysis of collaborative interactions. Ideally, monitoring will help not only to find the weaknesses of the group –a difficult task in itself– but also, with the aid of the computer, to overcome those weaknesses. It is possible to include in software tools mechanisms both to evaluate the collaborative learning process and to improve it. In a series of preliminary experiments in CSCL environments, it has been observed that groups with little experience in collaborative work do not understand, use or adopt cooperation strategies well (Collazos et al., 2002). Establishing common goals is an important component of strategy since actions cannot be interpreted without referring to the shared goals, and reciprocally, goal discrepancies are often revealed through disagreements on action (Dillenbourg et al., 1999). Members of a group do not only develop shared goals by negotiating them, but they also become mutually aware of these goals. TeamQuest includes a discussion environment that group members can use during a break. Breaks may be taken at any time during play. They provide opportunities for analysis of the work done, thus allowing the definition and reinforcement of common goals.

Monitoring can also help CSCL environment designers to improve their designs. For example, Collazos et al. have developed a mechanism called Negotiation Table, in which one widget supports discussions within the learning group and another supports monitoring of the tasks done by the group (Collazos et al., 2003b). These widgets are intended to improve the strategic aspect of group work. The information registered by the indicators permits the designers to modify or incorporate new mechanisms according to the information revealed by monitoring the collaborative activity.

The indicators we have developed permit evaluators to identify some weakness in the collaboration process in order to design strategies to better support it. As we mentioned in the first part of this article, however, measurement of

collaboration is not an easy task. Although we have only briefly mentioned variables that correspond to students' personal development as a result of participation, we believe these measures are also important. They can give evaluators insights into the collaborative process performed and the perception of each user with respect to their participation within the group. They could, for example, be incorporated at the end of a collaborative game using a brief questionnaire or open ended question to gather students' perceptions of their experience. Analysis of participants' answers could be used to determine if the group is able to self-evaluate or if they were able to construct a shared understanding of the problem. Such additional indicators could be compared with the system-based measures to understand which aspects of participation and interaction in the CSCL process are associated with users' perceptions and personal development.

In this project we did not develop indicators of social aspects of participation because the activities that we constructed for this initial test of the approach were activities for small groups working on activities that could be completed in a short time period. In real life collaborative learning, we recommend, however, evaluation of the social aspect as well as the aspects of the collaboration process measured here.

It is also important to note that collaborative learning processes are influenced by the personal style and individual behavior of every member of the group. In our collaborative games, for example, we noticed that group members behaved and communicated in consistent ways regardless of the role they were playing, coordinator or participant.

Although our indicators measure the collaboration process within a group, it is also possible to observe the individual contributions of every member in any group (Constantino-Gonzalez et al., 2000). This would permit a more specific analysis of interaction (movements and message) to evaluate the performance of every group member in their own group.

Conclusions and further work

Understanding the collaborative process of learning in groups is an interesting research field. In the case of collaborative activities, performing a task well implies not only having the skills to execute the task, but also collaborating well with teammates to do it. This complexity offers opportunities to develop tools and techniques for improving collaboration.

In this paper we have presented a set of indicators and software tools that have allowed us to experiment in the evaluation of collaborative work, and in particular, to study the collaborative processes that occur during collaborative learning. To evaluate collaborative processes, we proposed five system-based indicators and some indicators based on participants' psychological responses to the process of participation. We do not claim these are the only or the best indicators that could be developed to this end, but rather that they provide a direction to pursue in understanding and evaluating the process of CSCL. Nonetheless, these indicators were able to provide some insight into the collaborative work done by groups in our experiments. The system-based indicators can be used to detect group weaknesses in the collaborative learning process and to propose mechanisms to improve them. In this way, they can be used for both formative evaluation while students are collaborating using CSCL and summative evaluation once collaboration is complete. The meta-response indicators can be used for summative evaluation of the process.

Further work is needed to study the influence of many variables we did not isolate in our experimentation. Such variables include: genre or subject of the collaborative task, age, culture, homogeneous vs. heterogeneous groups, etc. Other experiments could also be made by changing the CSCL environments. Changes might include allowing broadcast messages or allowing the group to slightly modify the rules of a game (e.g., forcing the coordinator to receive all messages from members before enabling moves). Additionally, refinements might be made to the system-based indicators and experiments conducted to identify how the indicators behave when used to alert teachers and group members to aspects of the collaborative process that can be improved. Finally, the results of process tests can be compared with traditional tests of the success of CSCL to confirm that improvements in the CSCL process translate into improvements in the outcomes of CSCL.

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