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Supporting Social Interaction in an Intelligent Collaborative Learning System

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Abstract: Students learning effectively in groups encourage each other to ask questions, explain and justify their opinions, articulate their reasoning, and elaborate and reflect upon their knowledge. The benefits of collaborative learning, however, are only achieved by active, well-functioning teams. This paper presents a model of collaborative learning designed to help an intelligent collaborative learning system identify and target group interaction problem areas. The model describes potential indicators of effective collaborative learning, and for each indicator, recommends strategies for improving peer interaction. This collaborative learning model drove the design and development of two tools that automate the coding, and aid the analysis of collaborative learning conversation and activity. Empirical evaluation of these tools confirm that effective learning teams are comprised of active participants who demand explanations and justification from their peers. The distribution of conversational skills used by members of a supportive group committed to their teammates' learning is compared to that of an unfocused, unsupportive group. The results suggest that structured, high-level knowledge of student conversation in context may be sufficient for automating the assessment of group interaction, furthering the possibility of an intelligent collaborative learning system that can support and enhance the group learning process.

INTRODUCTION

The rapid advance of networking technology has enabled universities and corporate training programs to reach out and educate students who, because of schedule or location constraints, would not otherwise be able to take advantage of many educational opportunities. This new technological capability demands software that can support structured, on-line learning activities; thus we have recently seen the rapid development of computer-supported collaborative learning (CSCL) systems (Guzdial et al., 1997; Jermann and Dillenbourg, 1999; Scardamalia and Bereiter, 1994; Singley, Fairweather, and Swerling, 1999; Suthers, Weiner, Connelly, and Paolucci, 1995). CSCL systems offer software replicas of many of the classic classroom resources and activities. They may provide shared workspaces, on-line presentations, lecture notes, reference material, quizzes, student evaluation scores, and facilities for chat or on-line discussions. Successful distance learning programs around the globe have proven almost all of these tools successful. All but one – the support for on-line learning communication. Chat tools and bulletin boards (Blackboard, Inc., 1999; O'Day, Bobrow, Bobrow, Shirley, Hughes, Walters, 1998; Bruckman and Bonte, 1997) enable students to participate in on-line discussions, but provide no guidance or direction to students during or after these dialogue sessions.

In the classroom, effective collaboration with peers has proven itself a successful and uniquely powerful learning method (Brown and Palincsar, 1989; Doise, Mugny, and Perret-Clermont, 1975). Students learning effectively in groups encourage each other to ask questions, explain and justify their opinions, articulate their reasoning, and elaborate and reflect upon their knowledge, thereby motivating and improving learning. These benefits, however, are only achieved by active and well-functioning learning teams (Brown and Palincsar, 1989; Brufee, 1999; Jarboe, 1996; Salomon and Globerson, 1989). Placing students in a group and assigning them a task does not guarantee that the students will engage in effective collaborative learning

behavior. While some peer groups seem to interact naturally, others struggle to maintain a balance of participation, leadership, understanding, and encouragement. Dysfunctional group activity devalues the benefits of collaborative learning, and may even devalue the overall learning. Traditional lecture-oriented classrooms do not teach students the social skills they need to interact effectively in a team, and few students involved in team projects or exposed to integrated working environments learn these skills well (Johnson, Johnson, and Holubec, 1990). The most effective instructors teach students both the cognitive skills necessary to learn the subject matter, and the social skills they need to communicate well in a team.

Students learning via CSCL technology need guidance and support on-line, just as students learning in the classroom need support from their instructor. Educational researchers and technologists developing CSCL tools (Capozzi, Rothstein, and Curley, 1996) agree that group members do not necessarily have the social interaction skills they need to collaborate effectively. They recognize that students need practice, support, and guidance in learning these skills. Blumenfeld, Marx, Soloway, and Krajcik (1996) emphasize that, "while considerable research has examined small-group collaboration, there is no comparable body of experience for the use of technology-supported small groups" (Blumenfeld et al., 1996, p. 39). The work discussed here aims to address this research gap by developing an understanding of the support needed for social interaction in technology-supported group learning activities.

This paper describes ongoing research in the analysis of on-line peer-to-peer communication with the aim of promoting effective peer interaction in an Intelligent Collaborative Learning System. The analysis focuses on identifying those characteristics of interaction that contribute positively toward effective collaborative learning. This approach is reflected in Dillenbourg's (1999) view, when he states that, "One should not talk about the effects of collaborative learning in general, but more specifically about the effects of particular categories of interactions" (Dillenbourg, 1999, p. 16). These categories of interaction break down and describe the behavior of effective learning teams, laying the foundation for a complete categorical model of collaborative learning. Strategies for promoting effective interaction in each category could serve as tools for supporting collaborative learning activities in an Intelligent Collaborative Learning System (ICLS¹). An ICLS, embodying a model describing elements of effective collaborative learning and their support strategies, need only analyze the group conversation and activity to select the most appropriate strategy. This paper will present such a model, the Collaborative Learning Model, and will discuss the steps taken toward developing a system that uses this model to analyze and support collaborative learning interaction.

The first part of this paper discusses related research in analyzing and supporting collaborative learning conversations, and presents the first half of the Collaborative Learning Model, describing potential indicators of effective collaborative learning behavior. The second part highlights the facet of the Collaborative Learning Model focused on conversation skills, and relates it to recent findings from an empirical collaborative learning study. The third part of this paper presents the second half of the Collaborative Learning Model, which proposes implementation strategies an Intelligent Collaborative Learning System could employ to help groups improve their social interaction.

RELATED RESEARCH

The goal of this research is to enhance existing CSCL environments by applying artificial intelligence-based algorithms to dynamically analyze student actions and group conversation, and provide empirically grounded support to learning teams. Analyzing group conversation, however, poses its own challenges. Cahn and Brennan (1999) explain that a system can represent or model a dialogue using only the "gist" of successive contributions; a full account of

¹ The acronym ICLS was first used by McManus and Aiken (1993) as a specific system name, but has since been used more generally. The acronym is now used interchangeably with Intelligent CSCL in the literature.

each contribution, verbatim, is not necessary. Previous work has established promising research directions based on approaches that adopt this idea.

The Coordinator (Flores, Graves, Hartfield, and Winograd, 1988) attempted to assimilate the data needed to study organizational interaction by having users communicate their activities to each other using menus of conversation acts (such as request, promise, and accept). This system provided no support or guidance to the users, and attempted to make implicit commitments of speech acts explicit; consequently, the first versions were often regarded as overly coercive.

McManus and Aiken (1995) developed the Collaborative Skills Network, a taxonomy of conversation acts based on work by Johnson, Johnson, and Holubec (1990). Each conversation act in the taxonomy was assigned a key phrase or sentence opener (such as "Do you think" or "I disagree because") indicating the act's intention. Students communicated through a sentence opener interface by initiating each contribution with one of the key phrases, giving the system information about the users' intentions. McManus and Aiken's system imposed a strict ordering on the students' conversation act usage, defining which acts should appropriately come before and after other acts. Recognizing sequences of effective student interaction is key, however it may not be necessary to script students' conversations to obtain the desired results, given that effective group support strategies are utilized.

Baker and Lund (1996) compared the problem solving behavior of student pairs as they communicated through both a sentence opener interface and an unstructured chat interface. They found that the dialogue between students who used the sentence opener interface was more task focused. These results may have been influenced by the fact that the first set of openers on their interface (hence the openers most often considered in reading left to right) were problem (task) related, whereas the first set of openers on the interface described in this paper are Active Learning conversation acts. These acts are designed to capture students' critical question asking and information providing skills, along with students' ability to motivate their team members. The next section elaborates on the importance of these skills.

Jermann and Schneider's (1997) subjects could choose, for each contribution, to type freely in a text area, or to select one of four short cut buttons, or four sentence openers. Jermann and Schneider discovered that, in fact, it is possible to direct the group interaction by structuring the interface, as Baker and Lund (1996) suggest. Furthermore, they found that the use of the sentence openers was more frequent overall than that of the free text zone (58% vs. 42%). The idea of directing student interaction through a structured communication interface seems attractive, especially since it suggests the possibility of increasing a group's engagement in Active Learning. This concept alone, however would not suffice to support the group learning process. Students need feedback and guidance to learn effectively in groups.

Matessa (1999) compared the performance of dyads communicating through restricted (speech act based) and unrestricted (free text) communication interfaces, while solving a graph completion task. He found no significant differences in these two cases in the number of turns to complete the task, the time to complete the task, and the final score. He did find that the subjects using the unrestricted interface practiced more planning and meta-cognitive acts than those using the restricted interface, however this was probably because the restricted interface did not support this type of communication.

Robertson, Good, and Pain (1998) evaluated their sentence opener interface, BetterBlether, as an integral part of a primary school (11 year olds) curriculum. Although these children did not frequently use sentence openers which promoted justification and elaboration, the teacher felt that the interface helped the children improve their interaction with peers. The logged conversations also helped the teacher determine which skills to focus on in her classes.

This research takes previous work in structuring learning communication one step further by seeking to distinguish those interactions which are characteristic of effective group interaction from those which are not, and by establishing a framework for providing just-in-time support for students' changing social and pedagogical needs. The first step toward establishing criteria for evaluating learning interaction is understanding the characteristics of effective collaborative learning teams.

CHARACTERISTICS OF EFFECTIVE COLLABORATIVE LEARNING TEAMS

Ideally, an intelligent collaborative learning system would be able to understand and interpret a group's conversation, and could actively support the students during their learning activities. Monitoring, understanding, and facilitating collaborative learning activities begins with an understanding of the behaviors that characterize effective collaborative learning interaction.

The Collaborative Learning (CL) Model (Soller, Goodman, Linton, and Gaimari, 1998) describes potential indicators of effective collaborative learning teams based on a review of research in educational psychology and computer-supported collaborative learning (Brown and Palincsar, 1989; Jarboe, 1996; Johnson, Johnson, and Holubec, 1990; Koschmann, Kelson, Feltovich, and Barrows, 1996; McManus and Aiken, 1995; Teasley and Roschelle, 1993; Webb, 1992), and empirical data from a study conducted as part of this research (Soller, Linton, Goodman, and Gaimari, 1996). For each indicator of effective collaborative learning, the CL Model proposes strategies (described in detail later) for promoting effective peer interaction. The model is designed to help an Intelligent Collaborative Learning System recognize and target group interaction problem areas. Once problems are detected, the system can take actions to help students collaborate more effectively with their peers, improving individual student and group learning. In addition, the CL Model provides a set of criteria for evaluating the system after development.

The study was conducted during a five day course in which students learned and used Object Modeling Technique (OMT) (Rumbaugh, Blaha, Premerlani, Eddy, and Lorensen, 1991), an object-oriented modeling and design methodology, to collaboratively design object-oriented systems. The students worked in groups of four or five, and were videotaped using ceiling-mounted cameras. The videotape transcriptions were coded with a speech act based coding scheme (described later in this section), and studied through summary and sequential analysis techniques.

The characteristics studied and seen to be exhibited during effective collaborative learning interaction fall into five categories: participation, social grounding, active learning conversation skills, performance analysis and group processing, and promotive interaction. The following five subsections describe these categories and their corresponding characteristics.

Participation

A team's learning potential is maximized when all the students actively participate in the group's 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 (Jarboe, 1996). Encouraging active participation also increases the likelihood that all group members will learn the subject matter, and decreases the likelihood that only a few students will understand the material, leaving the others behind.

Participation statistics, if considered alone, may be a poor indicator of student learning. The second part of this paper provides empirical evidence that such information, considered in the context of the other Collaborative Learning Model facets with attention to factors such as a student's level of acknowledgement, may provide a reasonable account of the student's learning experience.

Social Grounding

Teams with social grounding skills establish and maintain a shared understanding of meanings (Teasley and Roschelle, 1993). The students take turns questioning, clarifying and rewording their peers' comments to ensure their own understanding of the team's interpretation of the problem and the 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" (Roschelle and Teasley, 1995, p. 76).

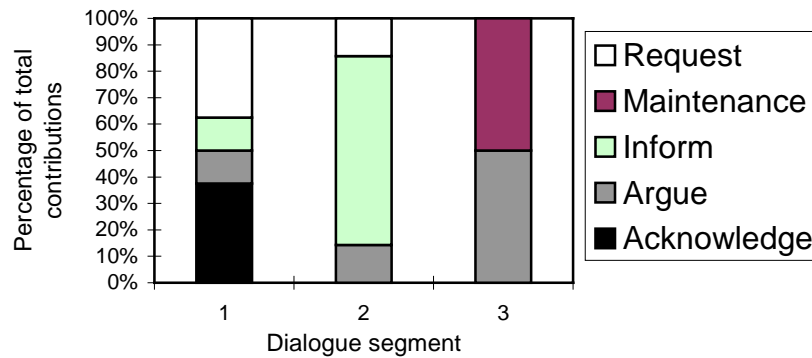


Figure 1. Summary of one student's contribution types over three consecutive dialogue segments

Analysis of the data collected from our study (Soller et al., 1996) revealed that students in effective collaborative learning teams may use role swapping to help prompt the turn-taking behavior that contributes to social grounding. Members of effective groups naturally take turns playing characteristic roles, switching their roles between dialogue segments (see Burton's dissertation (1998) for a more in-depth analysis of productive role switching behaviors). The beginning of a new dialogue segment is identified by the start of a new context, often initiated by sentence openers such as, "OK, Let's move on", "Now, this is the complicated part", or "Now what about this". For example, Figure 1 shows data from one student who naturally played three different roles during three consecutive dialogue segments. Qualitative analysis of the transcript shows that the student played the role of a questioner during the first segment, asking several clarification questions such as, "What's that mean?" He played an advisor during the second segment, making specific recommendations to the group. During the third segment, he played a quite different role, marked by conformance and commitment to maintain progress on his teammates' solution. The transcript was coded using conversation acts (Searle, 1969) such as Request, Inform, and Maintenance (described in the next section). The student's role swapping behavior, present in the conversation transcript, was also reflected in his conversation act usage. While playing the role of a questioner, he used a majority of conversation acts from the category Request; while playing the role of an advisor, he used a majority of conversation acts from the category Inform; and while attempting to maintain his team's progress, he used a majority of conversation acts from the categories Argue and Maintenance. This supports the idea that a student's role may be partly, or fully (Zapata and Greer, 1999), determined by the types of conversation acts he is using.

Active Learning Conversation Skills

The quality of communication in group discussions influences the team members' learning experience and achievement (Jarboe, 1996). Skill in learning collaboratively means knowing when and how to question, inform, and motivate one's teammates, knowing how to mediate and facilitate conversation, and knowing how to deal with conflicting opinions. Jarboe (1996) explains the importance of these conversation skills and the consequences of their uninformed use:

One can imagine two groups arriving at exactly the same consequences, yet one discussion might be marked by sarcastic tones and rigidity whereas another group presents its ideas supportively and tentatively. One group may build on each others' ideas to identify the consequences, but in the other group the final list is merely an aggregation of the individual contributions. And one group may disband with relief while the other looks forward to the next meeting. The sheer presence of an idea is one thing; the way it is presented is another; and its impact on group

process is also another. Particularly when a procedure under inquiry speaks to the social dimension of the group, then quality of communication must surely be considered. (Jarboe, 1996, p. 374)

Jarboe’s two groups may have arrived at the same solution, however they engaged in very different processes. Participation in the collaborative learning process, particularly for active learners in supportive teams, helps students improve the meta-level communication skills that transfer easily to learning in other domains. Active learners ask questions to improve their own or their peers’ understanding; they elaborate, clarify, and justify their arguments when prompted to by their peers, and they encourage and motivate their team members.

The Collaborative Learning Conversation Skills Taxonomy² (Figure 2) illustrates the conversation skills most often exhibited during collaborative learning and problem solving, based on our studies (Soller et al., 1996) (also see next section). The taxonomy is designed to facilitate recognition of active learning conversation. It breaks down each learning conversation skill type (Active Learning, Conversation, and Creative Conflict) into its corresponding subskills (e.g. Request, Inform, Acknowledge), and attributes (e.g. Suggest, Rephrase). Each attribute is assigned a short introductory phrase, or sentence opener, which conveys the appropriate dialogue intention. Table 1 offers brief descriptions of the subskill categories. The next section discusses the use of sentence openers in more detail.

Table 1. Definitions of Collaborative Learning Conversation Skills and Subskills

Active Learning	Request	: Ask for help/advice in solving the problem, or in understanding a team-mates comment.
	Inform	: Direct or advance the conversation by providing information or advice.
	Motivate	: Provide positive feedback and reinforcement.
Conversation	Task	: Shift the current focus of the group to a new subtask or tool.
	Maintenance	: Support group cohesion and peer involvement.
	Acknowledge	: Inform peers that you read and/or appreciate their comments. Answer yes/no questions.
Creative Conflict	Argue	: Reason (positively or negatively) about comments or suggestions made by team members.
	Mediate	: Recommend an instructor intervene to answer a question.

The students who benefit most from collaborative learning situations are those who encourage each other to justify their opinions, and articulate and explain their thinking. Active Learning conversation skills, such as Encourage, Explain, Justify, and Elaborate, describe the core communication activities of effective learning groups. The three subskill categories encompassing Active Learning are Inform, Request, and Motivate.

Performance Analysis and Group Processing

Group processing exists when groups discuss their progress, and decide what behaviors to continue or change (Johnson, Johnson, and Holubec, 1990). Group processing can be facilitated by giving students the opportunity to individually and collectively assess their performance. During this self evaluation, each student learns individually how to collaborate more effectively with his teammates, and the group as a whole reflects on its performance.

² The structural basis for the Collaborative Learning Conversation Skills Taxonomy was provided by McManus and Aiken’s (1995) Collaborative Skills Network, which structures and extends the cooperative learning skills defined by Johnson, Johnson, and Holubec (1990).

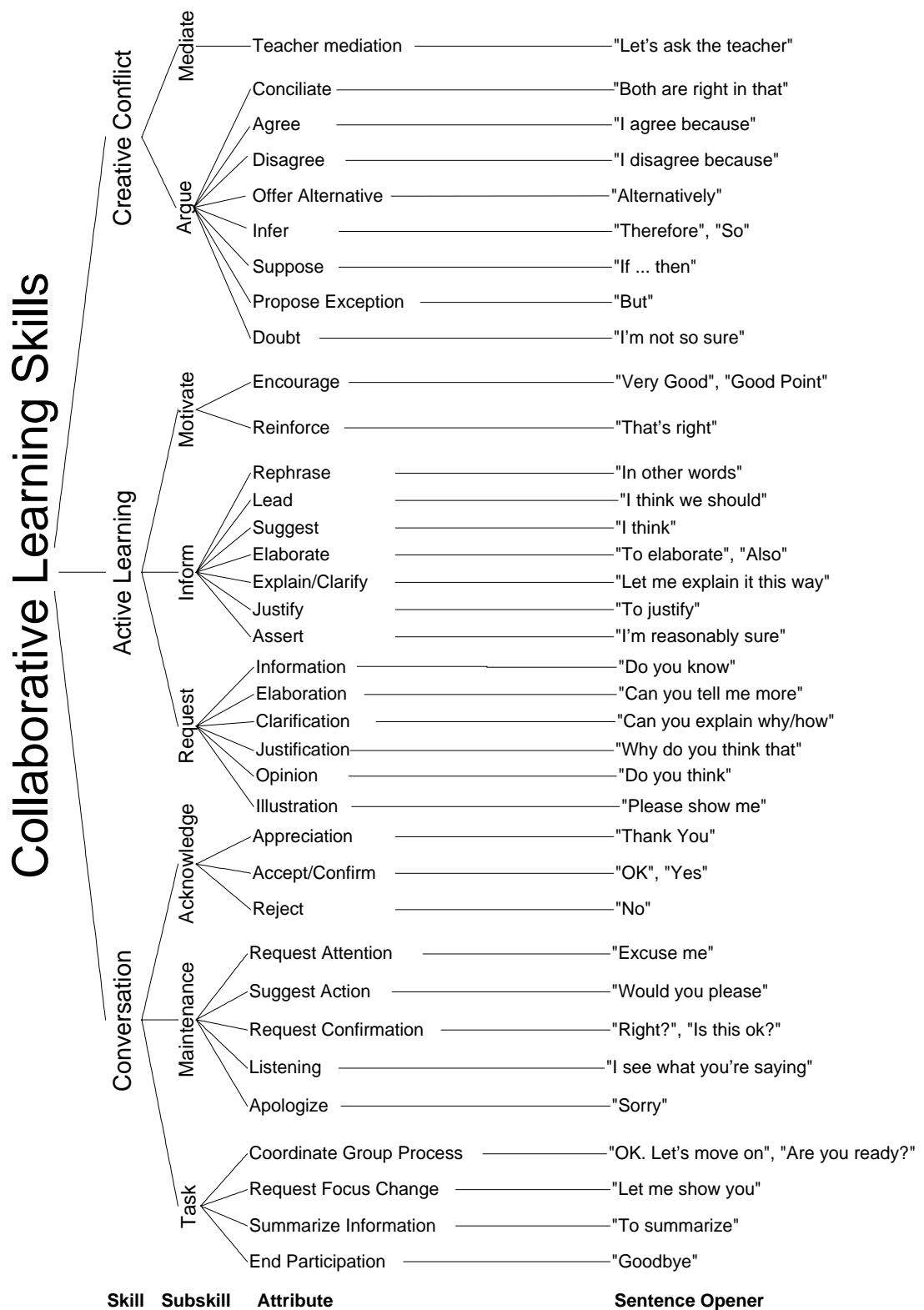


Figure 2. The Collaborative Learning Conversation Skill Taxonomy (structure adapted from McManus and Aiken's (1995) Collaborative Skills Network)

Promotive Interaction

A group achieves *promotive interdependence* when the students in the group perceive that their goals are positively correlated such that an individual can only attain his goal if his team members also attain their goals (Deutsch, 1962). In collaborative learning, these goals correspond to each student's need to understand his team members' ideas, questions, explanations, and problem solutions.

Students who are influenced by promotive interdependence engage in *promotive interaction*; they verbally promote each other's understanding through support, help, and encouragement (Johnson, Johnson, and Holubec, 1990). If a student does not understand the answer to a question or solution to a problem, his teammates make special accommodations to address his misunderstanding before the group moves on. Ensuring that each student receives the help he needs from his peers is key to promoting effective collaborative interaction.

ANALYZING COLLABORATIVE LEARNING CONVERSATION

Models of social interaction, such as the Collaborative Learning Model described in the previous section, provide some assistance in identifying the types of problems that may arise during collaborative learning sessions. These models have been successfully applied to classroom practice, however they present a view of effective social interaction at a level of abstraction too high to directly implement in a system. Whereas a classroom teacher facilitating a learning group may be guided by these models in deducing situations in which a group needs explanation or encouragement, a software agent in an Intelligent Collaborative Learning System, playing the role of a group facilitator, must be able to analyze a group's interaction based on the students' communication patterns and problem solving actions.

Although the Collaborative Learning Model was designed to draw upon various established social interaction models to form a comprehensive model that could be directly applied by an adaptive collaborative learning environment, this research quickly uncovered the need for a model operating at an even lower level of abstraction and integrating linguistic and social considerations. An Intelligent Collaborative Learning System with the knowledge and skills to determine how to promote effective student interaction in a group must be able to dynamically analyze peer-to-peer conversation and actions, identify a group's strengths and weaknesses, and determine which methods and strategies to apply in order to best further the group learning process. Developing a system to analyze peer-to-peer communication, however, is not a trivial task since even the latest natural language understanding technologies today combined with CSCL tools are still limited in their ability to understand and interpret student communication.

This section describes the empirical evaluation of two collaborative learning tools that automate the coding and initial analysis of collaborative learning interaction and activity. The study was designed, in part, to evaluate the potential for more advanced tools that can analyze, support, and enhance the students' interaction based on the Collaborative Learning Model.

The dynamic coding of student dialogue is made possible through a structured communication interface that requires students to begin each contribution with a short suggestive phrase, or *sentence opener*, such as, "I think", "Please show me", or "Do you know". Sentence openers provide a natural way for users to identify the intention of their conversational contribution without fully understanding the significance of the underlying communicative acts. Table 2 shows a dialogue, taken from our study, in which Rita³ explains to Chris why the group needs to consider the number of playgrounds. The sentence openers are italicized. Rita explains that determining the number of playgrounds will help the group decide how to model the multiplicity of the relation between the school and its playground(s).

³ The names of subjects have been changed to protect their privacy.

Table 2. Rita helps Chris understand the concept of multiplicity. Sentence openers are in *italics*.

Student	Subskill	Attribute	Sentence
Rita	Inform	Suggest	<i>I think</i> schools have zero or 1 or 2 playgrounds, usually
Rita	Inform	Justify	<i>To justify</i> sometimes there is a separate playground for the youngest kids
Chris	Request	Justification	<i>Why</i> are we questioning the number of playgrounds?
Rita	Inform	Explain/ Clarify	<i>Let me explain it this way</i> Chris – we needed to make the multiplicity on the school/playground link

During the study (described in detail in the next section), a structured, sentence opener-based communication interface (Figure 3) with a dynamic tagging and logging facility served as the basis for interpreting the group conversation. The interface contains groups of sentence openers organized in categories that are easy to understand. The sentence openers and communication categories represent the Collaborative Learning Conversation (CLC) Skills Taxonomy. The structured interface logs student conversation at three increasingly specific levels in accordance with the skills, subskills, and attributes defined in the CLC Skills Taxonomy (see Figure 2 and Table 1).

The goals of the case study motivating this research were:

1. To determine if learners would tolerate a sentence opener-based interface as a communication medium
2. To test the correctness and completeness of the Collaborative Learning Conversation Skills Taxonomy, and the naturalness of the taxonomy's sentence openers
3. To demonstrate the possibility of an Intelligent Collaborative Learning System that could dynamically analyze and advise collaborative learning conversations and activities

The remainder of this section discusses these goals in detail, and how they have been achieved.

A Case Study in Peer Learning Interaction

In order to determine if adult learners would tolerate using sentence openers, and to test the correctness and completeness of the Collaborative Learning Conversation Skills Taxonomy, groups of subjects were asked to communicate through a sentence opener-based chat interface (Collaborative Learning Interface, Figure 3) while solving object-oriented design problems using Object Modeling Technique (OMT) (Rumbaugh et al., 1991) (the same object-oriented modeling and design methodology students used in the first study).

Before the study commenced, a preliminary experiment was run to test the usability and stability of the software. One group of two, and two groups of three MITRE technical staff members participated in the preliminary experiment. All participants were familiar with the subject matter. Following the specifications of OMT, each group collaboratively solved one design problem using a specialized shared workspace, the OMT Editor⁴ (Figure 4). An example of a design problem is shown below.

Exercise: Prepare a class diagram using the Object Modeling Technique (OMT) showing relationships among the following object classes: school, playground, classroom, book, cafeteria, desk, chair, ruler, student, teacher, door, swing. Show multiplicity balls in your diagram.

⁴ The single-user version of the OMT Editor was developed by B. Wydaeghe and K. Verschaeve (1997).



Figure 3. The CL Interface

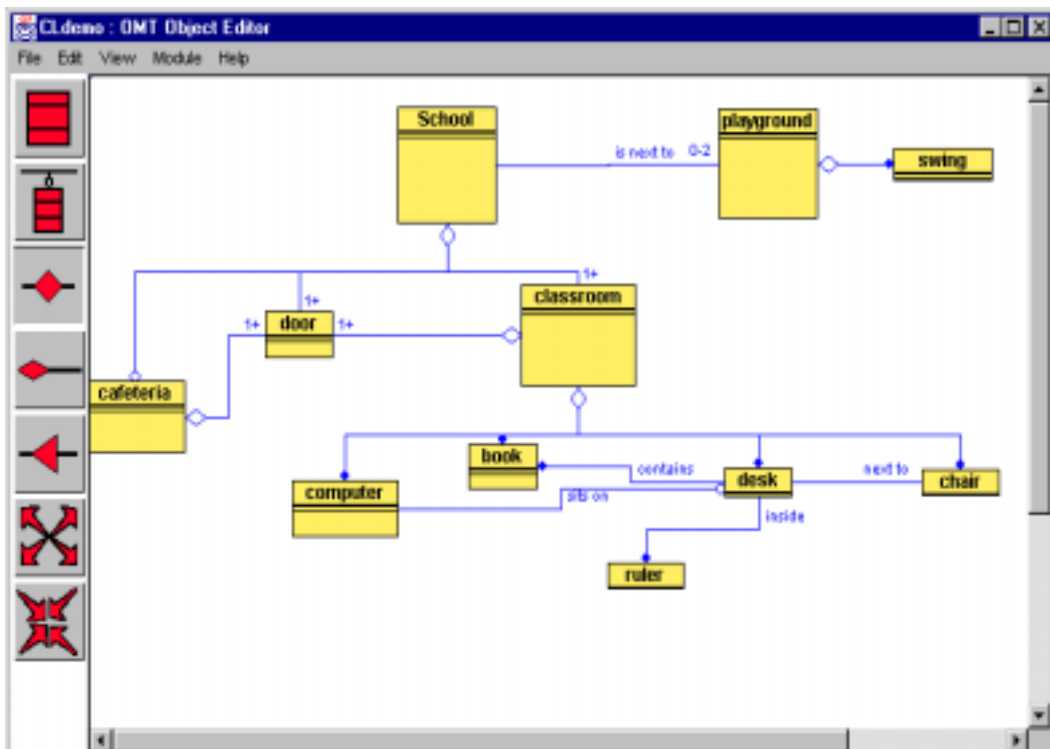


Figure 4. The shared OMT Editor

The group members communicated with each other through the Collaborative Learning (CL) Interface while solving the problem using the shared OMT Editor. Communicating through the CL Interface is similar to communicating through a familiar chat-style interface. To contribute to the group conversation, a student selects a sentence opener from one of the eight subskill categories shown on the lower half of the interface. The sentence opener appears in the chat box (the lower text window in the Figure 3), where the student can type in the rest of the sentence. Students view the group conversation as it progresses in the large window above the text box displaying the students' names and utterances. This sentence opener interface structures the group's conversation, making the students actively aware of the dialogue focus and discourse intent. The shared OMT Editor was provided to facilitate knowledge sharing, and ensure the teams converged on a single representation for the solution (Jeong and Chi, 1997).

The shared OMT workspace and CL Interface are 100% Pure Java "Hablets" – applets (of a sort) that are designed specifically to run within the NCSA Habanero collaborative framework, a distributed, open, Java environment (Chabert, Grossman, Jackson, Pietrowicz, and Seguin, 1998).

Requiring users to select a sentence opener before typing the remainder of their contribution may tempt them to change the meaning of their contribution to "fit" one of the openers, thus changing the nature of the collaborative interaction. For this reason, it is critical that the openers enable the widest possible range of communication with respect to the learning task. The openers shown in Figures 2 and 3 were originally developed from an analysis of face-to-face collaborative learning of OMT, and have been refined several times to accommodate users feedback and observed experiences. In order to evaluate whether or not users select the openers that appropriately represent their intended contribution, the researchers re-coded (by hand) the dialogues from the preliminary studies. On average, the re-coded attributes matched the students' sentence opener selections for 68% of the conversation. This percentage probably describes a worst-case scenario (although a follow-up analysis is needed to confirm this), since the version of the interface used in these studies was based solely on observed face-to-face interaction (from the videotaped study described earlier).

After the preliminary studies, the Collaborative Learning Conversation Skills Taxonomy and Collaborative Learning Interface were modified to account for the observed differences between face-to-face interaction and distributed collaborative interaction. Modifications included adding sentence openers specific to remote collaboration and tool control (such as "Would you please", "Please show me", and "Let me show you"), and making some frequently used sentence openers easier to find. Other added features included enabling a user to click on a collaborator's picture to address a comment or question specifically to him or her, and displaying the word "chatting" at the bottom of a user's picture while he is typing in the text box to let his team members know he will soon be contributing to the conversation. Before this feature was included, subjects often wondered if their team members were in the middle of typing, and waited to see if someone else had something to say, only to find out that all the group members were sitting around wondering the same thing. The students who were slower typers especially appreciated this feature.

"Short cut" buttons, which contained text such as "OK" and "Thank You", were also added to the interface, enabling students to quickly get an idea across without typing (Baker and Lund, 1996). These quick buttons help to discourage students from combining several thoughts into one contribution. For example, the result of Amy clicking the "OK" button is to send the message "Amy: OK" to the main chat window (the large text area in Figure 3). Amy cannot add a thought after "OK" (such as, "OK, Let's move onto the next problem.") until she chooses another sentence opener (in this case, "Let's move on"). Students participating in the preliminary studies frequently attached new thoughts to the end of "OK" openers. During the actual study, students were encouraged to use quick buttons and keep their contributions short, including only one thought per contribution. This modification helped to keep the coding and logging of student interaction more accurate.

Five groups of three MITRE technical staff members each participated in the actual study over the course of a month. Before each experiment, the students participated in a half hour interactive introductory lesson on OMT. They also received an OMT written tutorial, a quick

reference sheet on OMT notation, a sheet describing the subskills, attributes, and sentence openers in the Collaborative Learning Conversation Skills Taxonomy, and a design problem description. Since the subjects already knew each other (they worked on the same floor), they were not asked to participate in the usual team building exercises. During the introductory session, the subjects also practiced using the Collaborative Learning Interface and OMT Editor, and learned how to access the tools' help facilities. The subjects were then assigned to separate rooms and networked computers to begin solving the design problem. During the problem solving session, the researchers observed quietly in the back of the subjects' rooms. The groups were told to use as much time as they needed to construct and agree upon a suitable design. After the problem solving session, the students recounted their experience, and filled out a questionnaire.

The next two subsections summarize the observations made and the data collected from the study to date. The student action log (Figure 5), a specialized tagging and logging module integral to the Collaborative Learning Interface and OMT Editor, recorded the students' contributions to the group conversation, and actions on the shared OMT Editor. This module served as an automatic data gathering and structuring tool, which facilitated the analysis that follows.

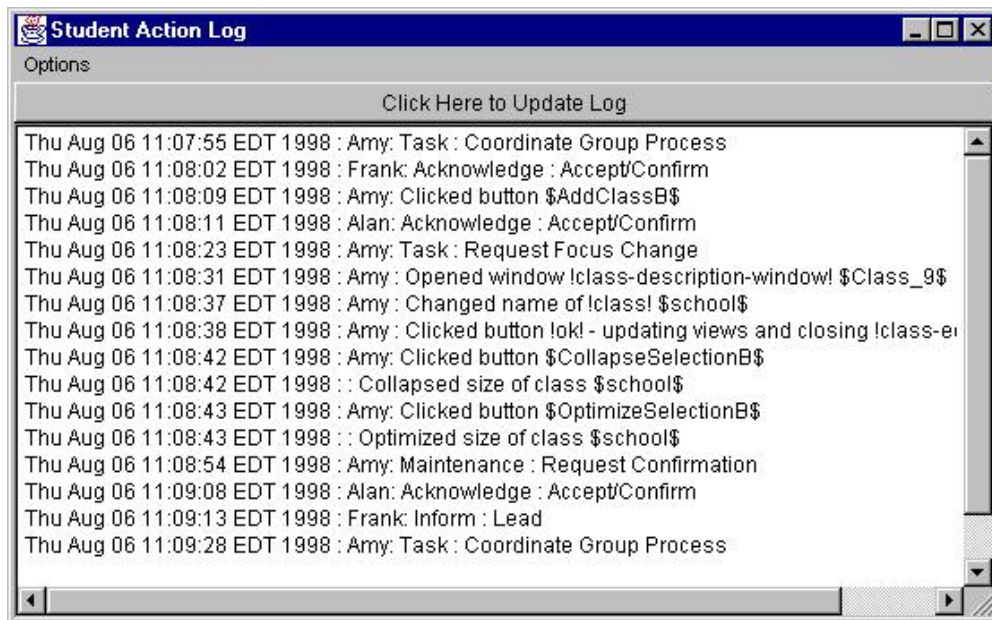


Figure 5. Student Action Log generated from student dialogue, and actions on shared OMT Editor

Observations from the Case Study

The five groups took from 1 to 1.5 hours to complete the design task described in the previous section. The researchers observed the students as they worked through the exercise, and individually administered questionnaires afterwards. This section describes some of the researchers' observations, and summarizes the subjects' responses to the questionnaire.

The Collaborative Learning Interface does not permit a user to type a statement in the text box without first choosing a sentence opener, however the interface does nothing to prevent a student from selecting a sentence opener, but then deleting it from the text box and typing in anything at all. Although most students in the study rarely took advantage of this flexibility, one student used it almost exclusively. Surprisingly, this student conscientiously ensured that the intention of the sentence opener he chose was equivalent to the communicative intention of his text. For example, in one case the student selected the opener, "Is this OK?", which represents

the “Request Confirmation” attribute from the “Maintenance” subskill category (see Figure 2), but then deleted the opener and typed, “I want to make sure [my teammate] agrees.”

The questionnaires administered after the problem solving phase gathered information about the subjects’ experience in collaboration, OMT, and chat tools. It also asked the subjects to evaluate the introductory lesson on OMT and Collaborative Learning Skills, and comment on the software’s usability and functionality. The last section of the questionnaire assessed the subjects’ attitude toward chat tools, degree of engagement and control, and learning of OMT during the study. Finally, the students commented on how they would feel about using the tools in a formal, collaborative course. The results of this questionnaire follow.

The subjects described the introduction to OMT as adequate. A few of the subjects felt the overview of the Collaborative Learning skills definitions a bit confusing, however none had any problems developing their own understanding of the categories by reading through the sentence openers available in each category. Almost all students had a few minor problems with the functionality of the OMT Editor. The students could not modify an OMT Editor element privately, without the other collaborators viewing and sometimes interfering with the modification process. In some groups, the students’ workspaces periodically needed to be synchronized to ensure all the group members were viewing the same diagram.

The subjects felt a high degree of engagement, but only a slight degree of control during the study. A few verbalized their desire to have some formal way of formulating a group plan or strategy for both assigning roles and performing the task. One student described the need for a “pass the chalk” concept of control, similar to the activity involved in using a blackboard while collaborating face-to-face.

The subjects liked the chat-style interface, however most of these users were positively biased towards chat tools in general. Although some of the subjects found having to choose a sentence opener somewhat restrictive, most subjects became more comfortable with the interface once they had a chance to experiment with it. One of the subjects occasionally wanted to say something “off the record”, and felt uncomfortable at times knowing that the system was logging his actions. Subjects also expressed their desire to display certain emotions (in particular, frustration and approval) through the interface. This feature may be added to the interface in the future.

On average, the students expressed slight interest in using these tools in a formal course, however there was a great deviation in responses. These results are surprising, since about half the students showed some interest in using a sentence opener-style interface in a formal course without being given a clear explanation for why their communication was being structured. The students who were not interested in using these tools in a formal course did show some interest after the researchers explained the motivation behind the sentence opener-based interface, and described the future payback (e.g. dynamic intelligent help) for using the interface.

No formal pre or post tests were administered during the study, however subjects were asked to rate their learning of OMT on a scale from -3 to 3. A score of -3 meant that the subject learned no OMT during the study; a score of 3 meant that the subject learned a lot of OMT during the study. Technical staff members at MITRE evaluate their own learning and determine what skills they need to improve every day as part of their jobs. For these subjects, self-assessing their learning during this study is akin to the self-assessment they perform regularly at work.

The results showed that those subjects who were already familiar with OMT from either a formal course or work experience (9/15) did not report learning OMT. The majority of those who did not already know OMT (6/15), however, did feel they learned OMT, and some felt they learned a lot. Since the subjects were volunteers and may not have been motivated to learn OMT, the fact that they may have learned as a consequence of participating in the study, means that involvement for these students in the collaborative learning experience alone may be an effective method for learning.

The students were not given help or guidance during the problem solving phase. It was evident, however, that coaching would have benefited both the individuals and the groups. Subjects in all groups attempted to ask questions of the observers, who were instructed not to help the students solve the problem. One subject expressed his desire for an on-line instructor,

who could help to distribute roles and manage the group interaction during the problem solving activity. One of the long-term goals of this project is to advise the development of an intelligent collaborative learning coach for promoting effective group learning behavior.

Data Analysis from the Case Study

Students who encourage each other to justify their opinions, and articulate and explain their thinking may benefit most from learning with peers. These Active Learning conversation skills (such as Encourage, Explain, Justify, and Elaborate) describe the core communication activities of effective learning groups. The three subskill categories encompassing Active Learning are Inform, Request, and Motivate (Table 1). This subsection will discuss some results of the study as they relate the students' use of Active Learning conversation skills.

Analysis of the data from this study⁵ revealed that the students who spent considerable effort (more than 30% of their total contributions) participating in the conversation by acknowledging their peers' comments did not feel they learned as much as the students who were actively engaged in the learning process, utilizing more Active Learning, Maintenance, Task and Argue conversation skills, and practicing less Acknowledgement. Figure 6 compares the percentage each subject participated in the group discussion with the percentage of their contributions comprised of acknowledgement (such as a simple yes, no, or okay). The subjects are shown, ranked along the horizontal axis, from those who felt they learned no OMT to those who felt they learned a lot of OMT.

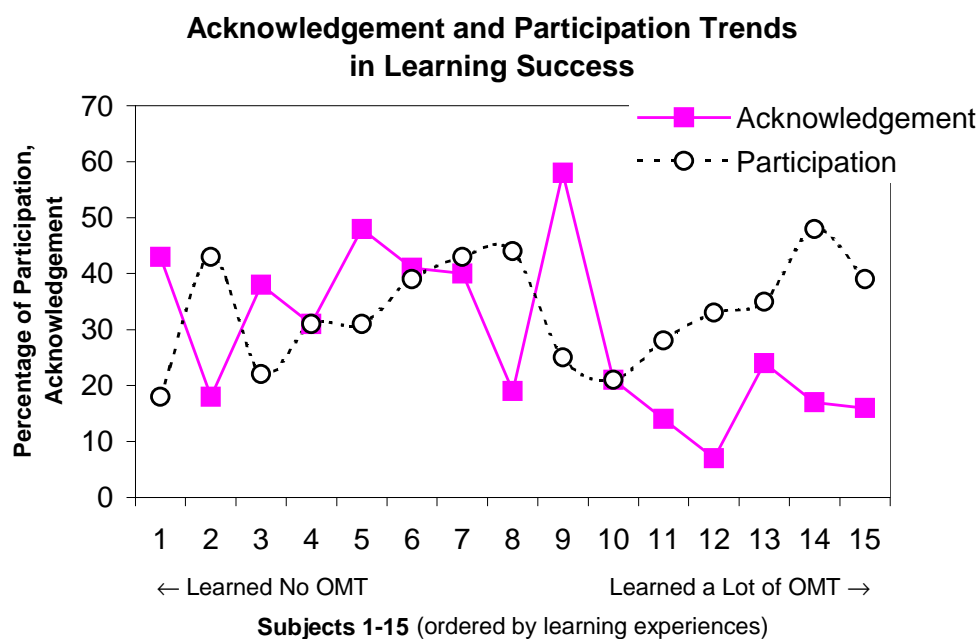


Figure 6. The students who participated more and acknowledged less felt they learned the most

No clear trend is evident for those subjects who felt they learned no OMT (subjects 1-5) or who felt indifferent to their learning (subjects 6-8). The level of acknowledgment for five of the seven students (subjects 9-15) who felt they learned a considerable amount of OMT, however, is significantly lower than their level of participation. These subjects represented both first-time learners (subjects 9, 10, 11, and 13) and non first-time learners (subjects 12, 14, and 15), eliminating the possibility that the trend showing a participation/acknowledgement difference is solely a characteristic of first-time learners. The subjects who felt they learned OMT during the study showed the largest difference between their acknowledgement and participation levels (22.5%). Those who felt indifferent to their learning showed a difference of 2.25%, and those

⁵ The results presented here describe trends in a small data sample, and do not imply statistical significance.

who felt they did not learn during the study showed a difference of -4% (their average level of acknowledgement was above their level of participation). Although these results are not statistically significant, they motivate further work along these lines toward uncovering similar trends that an intelligent system might use to understand the group interaction.

In all groups, the subjects' usage of Active Learning skills was roughly proportional to their degree of participation in the group conversation. The percentage of Active Learning contributions a student made to the group, as a percentage of his total contributions, was slightly suggestive of the degree to which that student felt he learned OMT. The percentage of Active Learning Requests was a more accurate predictor of learning for first-time learners (0.63) than for subjects who had prior knowledge and experience in the domain. Figure 7 shows the first-time learners' percentage of Active Learning Requests as a function of their learning assessment. The trend shown in the figure is suggestive, but not statistically significant, due to the small number of first time learners participating in the study.

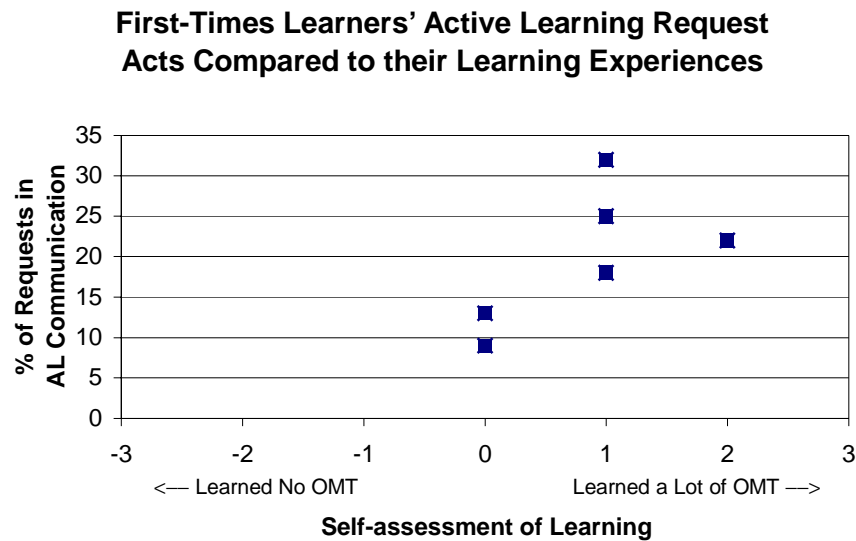


Figure 7. The first-time learners who ask more questions felt they learned more OMT

Although the number of questions asked by first-time learners seems to suggest their degree of learning success, this factor should not be singly predictive of their learning. A student asking a question will learn only if the group responds to his request for help by providing a relevant, adequately elaborated, understandable response (Webb, 1992). In general, the number of questions a student asks must be considered along with the quality and amount of support provided by his team members. In this study, most team members were very supportive of each other, and in many cases, students went out of their way to help their team members (e.g. Table 2; also see next section). The next section elaborates on the characteristic differences between a supportive group committed to the success of its members, and one which was not as supportive.

Closer Look at Two Groups

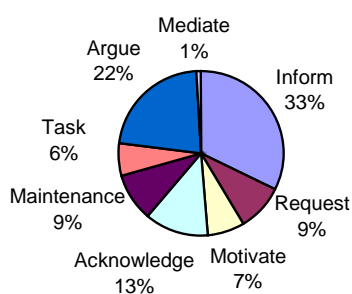
This section takes a closer look at two groups that participated in this study, and compares some telling characteristics of them. The students in one group were not as committed as those in another to helping their peers understand the subject matter. This was evident in the researchers' evaluation of the transcripts, the subjects' self-assessments, and the summaries of Collaborative Learning Conversation (CLC) skills. Figure 8 illustrates summaries of the total percentages of CLC skills used by a very supportive group (Group A), and an unfocused group (Group B) that was not as supportive of each other's learning, respectively. A supportive group is defined as one that fosters productive learning experiences for all its members by practicing the skills that

underlie the Collaborative Learning Model, described in the first part of this paper. Two of the three members of Group A felt they learned a lot about OMT during the study, whereas none of Group B's members reported learning OMT. In Group A, acknowledgement (as defined in Table 1) accounted for only 13% of the conversation, while in Group B, acknowledgement accounted for 40% of the conversation. Results from all groups in this study showed clearly that the percentage of the conversation comprised of acknowledgement provides clues about the quality of learning in the group. Students who felt they learned the most during the study were members of groups with lower acknowledgement activity (also see Figure 6).

The pie chart summarizing Group A's collaborative interaction shows a problem-solving conversation balanced by all the CLC skills. A summary of the statistics for this group's interaction shows group members participating evenly, with all students utilizing an almost equal number of Active Learning skills. These students also gave each other ample opportunity to draw on the shared OMT tool. This was an extremely balanced group in both conversation and student OMT tool control.

The pie chart summarizing Group B's interaction shows that Acknowledge and Inform contributions comprised 74% of the conversation. Very little group maintenance and task management activity occurred in Group B, compared to Group A. A closer examination of Group B revealed that the few questions group members did ask each other went unanswered. The student who participated in the conversation the least completed the group's OMT design almost exclusively on his own. This student had taken a formal course on OMT prior to the study, whereas the others students were not as experienced. Consequently, the first-time learner in this group did not feel that he learned OMT during the study.

Group A: Balanced, Supportive



Group B: Unbalanced, Unsupportive

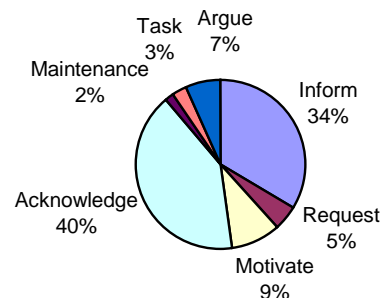


Figure 8. Summary of Collaborative Learning Conversation Skills for a very supportive group (Group A), and one which was not particularly supportive (Group B)

Both Groups A and B produced comparable solutions to the problem. In collaborative learning activities, however, a team that produces a good solution to the problem does not necessarily satisfy the intended goal of helping all the team members learn the subject matter (and learning how to work together as a result (Burton, 1998)).

The analysis presented in this section demonstrates that summaries of student communicative actions and actions on a shared workspace may provide clues about the quality of interaction in a group. Understanding and verifying the presence of interaction trends that indicate effectiveness is the first step toward developing a low-level, computational model of social interaction that maintains the integrity of the Collaborative Learning Model. Further work is needed to characterize sequences of learning interaction that indicate effectiveness (and ineffectiveness), and to map the results of the summary and future sequential analyses to the five facets of the Collaborative Learning Model.

STRATEGIES FOR PROMOTING EFFECTIVE PEER INTERACTION

An Intelligent Collaborative Learning System that can analyze social interaction given summaries and sequences of low level communicative and workspace actions must then determine what actions to take to support the group learning process. Successful individualized coaching strategies have been identified by studying the characteristics of effective student/tutor interactions (Fox, 1993; Katz and Lesgold, 1993). Similarly, studying characteristics of effective student/student interaction may aid in the development of group support strategies. The next five subsections describe strategies an Intelligent Collaborative Learning System could employ to help students attain the skills required to excel in each of the five Collaborative Learning Model categories covered in the first part of this paper.

Encouraging Participation

An Intelligent Collaborative Learning System (ICLS) can encourage participation by initiating and facilitating round-robin brainstorming sessions (Jarboe, 1996) at appropriate times during learning activities. Consider the following scenario. An ICLS presents an exercise to a group of students. After reading the problem description to himself or herself, each group member individually formulates procedures for going about solving the problem. A student who is confident that he has the “right” procedure may naturally speak up and suggest his ideas, whereas the student who is unsure (but may actually have the best proposal) may remain quiet. During this phase of learning, it is key that all students bring their suggestions and ideas into the group discussion, especially since quiet students of lower ability have particular difficulty learning the material (Webb, 1992). The ICLS initiates and facilitates a round-robin brainstorming session a few minutes after the students have read the problem description. Each student in the group is required to openly state his rationale for solving the problem while the other students listen. Round-robin brainstorming sessions establish an environment in which each student, in turn, has the opportunity to express himself openly without his teammates interrupting or evaluating his opinion. An ICLS can help ensure active participation by engaging students in these sessions at appropriate times.

Personal Learning Assistants (PaLs), personified by animated computer agents, can be designed to “partner” with a student, building his confidence level and encouraging him to participate. Providing a private channel of communication (Koschmann, Kelson, Feltovich, and Barrows, 1996) between a student and his personal learning assistant allows the student to openly discuss his ideas with his PaL without worrying about his peers’ criticisms. A student’s PaL could help him develop his ideas before he proposes them to the other students. The personal learning assistant may also ask the student questions in order to obtain a more accurate representation of his knowledge for input to the student model. A more accurate student model allows coaching to better meet student needs.

Maintaining Social Grounding

An Intelligent Collaborative Learning System can model the turn-taking behavior that is characteristic of teams with effective social grounding skills (Roschelle and Teasley, 1995) by assigning the students roles (Burton, 1998) such as questioner, clarifier, mediator, informer, and facilitator (among others), and rotating these roles around the group for each consecutive dialogue segment. The beginning of a new dialogue segment is identified by the start of a new context, often initiated by sentence openers such as, “OK, let’s move on”.

One or more critical roles, such as questioner or motivator, may be missing in a group if there are too few students to fill all the necessary roles. A missing role can be played by a simulated peer, or *learning companion* (Chan and Baskin, 1988; Goodman, Soller, Linton, and Gaimari, 1998). The learning companion can be dynamically adapted to best fit the needs of the group, playing the role of critic during one dialogue segment, and facilitator during the next.

Identifying and characterizing the natural role switches that take place between dialogue segments will aid in further developing advanced strategies for maintaining social grounding through role playing.

Supporting Active Learning Conversation

Students solving open-ended problems, in which an absolute answer or solution may not exist, must explain their viewpoints to their peers, and justify their opinions. Assigning students open-ended activities encourages them to practice these essential Active Learning conversation skills. A learning companion, or simulated peer, in an Intelligent Collaborative Learning System can also encourage students to elaborate upon and justify their reasoning by playing the role of devil's advocate (Aïmeur, Dufort, Leib, and Frasson, 1997; Goodman et al., 1998; Jarboe, 1996).

Providing students with collaborative learning skill usage statistics (e.g. 10% Inform, 50% Request, 40% Argue) may raise their awareness about the types of contributions they are making to the group conversation. This capability, however, requires either the Intelligent Collaborative Learning System to understand and code the students' dialogue, or the students to tell the system from which skill categories their utterances belong. Sentence openers provide a natural and alternative method for obtaining this dialogue information.

Evaluating Student Performance and Promoting Group Processing

An Intelligent Collaborative Learning System can promote group processing by evaluating students' individual and group performance, and providing them with feedback. Students should receive individual evaluations in private, along with suggestions for improving their individual performance. The team should receive a group evaluation in public, along with suggestions for improving group performance.

The purpose of providing a group evaluation is to inspire the students to openly discuss their effectiveness while they are learning and determine how to improve their performance. This introspective discussion may also be provoked by allowing the students to collaboratively view and make comments on their student and group models (Bull and Broady, 1997; Hoppe, 1995).

Supporting Promotive Interaction

Webb (1992) outlines five criteria for ensuring that students provide effective help to their peers in a collaborative environment. These criteria are (1) help is timely, (2) help is relevant to the student's need, (3) the correct amount of elaboration or detail is given, (4) the help is understood by the student, and (5) the student has an opportunity to apply the help in solving the problem (and uses it!). The following paragraphs recommend strategies to address each criteria.

When a student requests help, the Intelligent Collaborative Learning System can encourage his teammates to respond in a timely manner. Assigning a mentor to each group member provides students with a personal support system. Student mentors feel responsible to ensure their mentee's understanding, and mentees know where to get help when they need it.

In response to their questions, students must be provided with relevant explanations containing an adequate level of elaboration. Their peers, however, may not know how to compose high-quality, elaborated explanations, and may need special training in using examples, analogies, and multiple representations in their explanations (Blumenfeld, Marx, Soloway, and Krajcik, 1996; Kumar, McCalla, and Greer, 1999). To increase the frequency and quality of explanations, and Intelligent Collaborative Learning System could strategically assign students roles such as "Questioner" and "Explainer" to help them practice and improve these skills.

Webb's fourth and fifth criteria can be met by an ICLS by observing and analyzing a student's workspace actions in conjunction with his communicative actions to determine whether or not a student understood and applied the help received.

Summary of the CL Model

The Collaborative Learning Model identifies the characteristics exhibited by effective learning teams, namely participation, social grounding, performance analysis and group processing, application of active learning conversation skills, and promotive interaction. This model provides Intelligent Collaborative Learning System developers with a framework and set of recommendations for helping groups acquire effective collaborative learning skills. Table 3 summarizes the strategies that address each of the five CL Model categories, and shows the candidate system components that might implement these strategies.

The left hand column of Table 3 lists the five facets of the Collaborative Learning Model, and the top row of the table lists candidate components of an intelligent assistance module in an Intelligent Collaborative Learning System. The table summarizes the strategies, discussed in this section, for helping groups achieve effectiveness in each of the model's five categories, and lists each strategy under the software component which might implement it. For example, the collaborative learning skills coach may be responsible for initiating and facilitating a round-robin brainstorming session, an activity designed to encourage participation. The instructional planning component (Vassileva and Wasson, 1996), typically responsible for selecting appropriate exercises to present to the students, might also select roles to assign to students, and determining when group members should switch roles.

Table 3. The Collaborative Learning Model support strategies that could be implemented by each Intelligent Collaborative Learning System component

Intelligent Collaborative Learning System Component					
Collaborative Learning Model Facet	Collaborative Learning Skill Coach	Instructional Planner	Student/ Group Model	Learning Companion	Personal Learning Assistant (PaL)
Participation	Facilitate round-robin brainstorming sessions	Determine when to initiate round-robin brainstorming sessions			Encourage participation
Social Grounding		Choose roles to assign to students, and rotate roles at appropriate times		Fill in missing roles in group	Ensure students are playing their assigned roles
Active Learning Conversation	Provide feedback on Collaborative Learning skill usage	Assign tasks that require students to practice Active Learning skills	Store student/ group Collaborative Learning skill usage statistics	Play devil's advocate to encourage active learning skill utilization	Encourage students to challenge or explain others' ideas
Performance Analysis & Group Processing	Provide feedback on group/ individual performance		Allow students to inspect and comment on their student/ group models		
Promotive Interaction	Ensure adequate elaboration is provided in explanations	Assign mentors or helpers to students	Update student/ group models when students ask for and receive help	Help students compose high-quality, elaborated explanations	

Table 3 provides a toolkit of strategies that an Intelligent Collaborative Learning System can use to help students learn the skills they need to excel in all facets of effective collaborative learning. In order to address a group's changing needs, the system must be able to select the most fitting strategy on demand. This involves observing and dynamically analyzing the

students' interaction, identifying the weakest facet of their interaction, and selecting a strategy to address this deficiency. The analysis presented in this paper suggests that data about student intentions, obtained from a sentence opener interface, and knowledge of student actions on a shared workspace, may provide clues about the quality of group interaction. The analysis performed thus far strongly suggests that further analysis may be promising in this regard. The next steps involve gathering more data to strengthen the claims made, and generalizing these claims so that the low-level observations can be directly linked to the Collaborative Learning Model facets. These steps are described in more detail in the next section.

DISCUSSION AND FUTURE WORK

Placing students in a group and assigning them a task does not guarantee that the students will engage in effective collaborative learning behavior. The Collaborative Learning Model described in this paper identifies the specific characteristics exhibited by effective collaborative learning teams, namely participation, social grounding, performance analysis and group processing, application of active learning conversation skills, and promotive interaction. The model suggests strategies, based on these characteristics, for promoting effective peer interaction. It is designed to help an Intelligent Collaborative Learning System recognize and target group interaction problem areas. Once targeted, the system can take actions to help students collaborate more effectively with their peers, maximizing individual student and group learning.

Selecting the proper strategies to apply to best further the group learning process requires an Intelligent Collaborative Learning System to dynamically analyze peer-to-peer conversation and actions. The level of information provided by the Collaborative Learning Interface, along with knowledge of student actions on a shared workspace, provides insight into the group interaction as shown by the analysis presented in this paper. The findings from this analysis, which was conducted at the conversation act level, concur with the findings from small group learning studies (Brown and Palincsar, 1989; Webb, 1992) in which large corpuses of peer dialogue were studied. Knowledge of conversational acts in context may potentially suffice for enabling an intelligent system to observe and draw inferences about the collaborative learning group.

The subjects for the studies described in this paper collaboratively solved Object-oriented modeling and design problems, an inherently collaborative domain with unclear constraints. This domain was chosen because it closely models the activities of research design teams in industry. Tasks that are traditionally performed individually, or that present clear constraints and goals may find results somewhat different from those drawn here.

The next step is to identify characteristic sequences of student interaction that yield productive learning opportunities. A summary analysis tells us, for example, how many questions each student asked, or how many explanations each student or group produced. It does not tell us if a particular explanation was offered in response to a peer's question, or if the explanation satisfied the question asker. This knowledge is hidden in the dialogue exchanges between students, and only recoverable through a low-level sequential analysis of the dialogue. Experiments are now underway to identify and analyze finite sequences of social interaction indicative of effective collaborative learning.

Identifying examples of interaction sequences exemplifying each of the five characteristics of effective collaborative learning (in the Collaborative Learning Model) will help to define these characteristics more concretely, facilitating their recognition by an Intelligent Collaborative Learning System. Analyzing these sequences against the structured foundation of the Collaborative Learning Model will guide the system in further understanding the group interaction and determining how to best support the group during the learning process. This understanding will also enable an intelligent coach, or learning companion (Chan and Baskin, 1988; Goodman et al., 1998) to intelligently guide and participate in the group conversation.

The goal of this research is to develop and implement methods for supporting and facilitating effective learning conversation. Structuring students' communication, and

explaining how structured communication patterns relate to effectiveness, is one strategy for assimilating the knowledge a system needs to dynamically and efficiently analyze peer-to-peer interaction. Once we can demonstrate the ability to promote effective interaction in collaborative learning groups using conversation act information from structured interaction, we can begin to explore less restrictive strategies, such as employing speech recognition and machine learning techniques to identify candidate sentence openers and cue phrases (Samuel, Carberry, and Vijay-Shanker, 1998) in peer communication.

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