Supporting Collaborative Learning With An Intelligent Web-Based System

Judith Israel, Department of Computer Science, Widener University, Chester, PA 19013, USA
judi@jlinet.com

Robert Aiken, Department of Computer and Information Sciences, Temple University, Philadelphia, PA 19122, USA
aiken@knight.cis.temple.edu

Abstract. This research describes an Intelligent Collaborative Support System (ICSS) that supports a collaborative effort by analyzing and modifying the collaborative process dynamically while employing a web-based interface. Based upon principles rooted in Computer-Supported Cooperative Work (CSCW), Intelligent Tutoring Systems (ITS) and Cooperative Learning (CL), this system extends the Group Leader paradigm to assist students working together in collaborative groups. Discussion skills are supported by examination of sentence openers chosen from a menu, keywords found in free-text sentence closers, student and group models, and historical database files. Groups are categorized and guided toward the optimal category of a high-performing cooperative group with positive interdependence. The use of the dialogue designated as creative conflict is mediated by an agent to assist in formulating a constructive discussion, serving as an instructional tool. Conflicts in the categorization of discussion skills exhibited in the sentence openers versus the sentence closers are resolved. Implemented in Java, the Group Leader module interacts with intelligent agents as it guides students working in groups remotely in the cross-platform environment provided by the Java Virtual Machine.

Keywords. Collaborative learning, communication skills, CSCL, dynamic classification

INTRODUCTION TO THE PROBLEM

Computer-supported collaborative learning (CSCL) tools are a natural outgrowth of today’s rapidly changing learning and work environments. As noted in Kiesler and Hinds (2002, 2004), technological advances in conjunction with changes in the global economy are increasing the geographic distribution of work in industries as diverse as banking, wine production, and clothing design. Work teams are spread across different cities or countries while their projects involve work in many locations. For example, the electronic community that created the original Linux computer operating system would suggest that distributed work arrangements can and should be flexible and innovative. At the same time, distributed work complicates workers’ professional and personal lives. Distributed work alters how people communicate and how they organize themselves and their work. Support for this distributed process is becoming increasingly important.

Although very often the terms “collaborative learning” and “cooperative learning” are used interchangeably, a distinction can be made that the goal of cooperative learning is for each student to independently contribute to the solution while individually performing his or her learning task (but not necessarily assisting other students to do so), while the goal of collaborative learning is for all students
to learn all the material together. It is collaborative learning upon which the ICSS is designed, thus focusing on the interdependence of students using the system while concurrently learning and working on the same project.

This paper describes the Intelligent Collaborative Support System (Israel, 2003) that is an enhancement and extension of a previous system, the Intelligent Collaborative Learning System (ICLS) of McManus (1995) as well as previous work of Soller and her colleagues (1998, 1999, 2001, 2003 & 2004) focusing on analyzing and supporting collaborative learning conversations. The ICSS supports a collaborative effort by analyzing and modifying the collaborative process dynamically while employing a web-based interface. The familiar interface of a browser enables distance and global compatibility. In addition, the ICSS addresses the issues of portability and inconsistencies in the classification of communication skills, as well as the further development of student and group models initiated in previous research. The primary goal is to assist members of a group to more effectively collaborate in solving a problem especially when they are working at a distance. The ICSS also provides support for students to learn the collaborative skills needed for a distributed work environment.

In the following sections we will discuss aspects of collaborative learning systems research that have been particularly applicable to our work, followed by a description of the Intelligent Collaborative Support System, its architecture and group leader component, the Student Models and Group Models we implemented, an evaluation of the system and our conclusions and future research.

**COLLABORATIVE LEARNING SYSTEMS AND RELATED WORK**

Since the early 1990s various research groups have been exploring how to build intelligent software systems that assist members working on a group project to better collaborate. One of the earliest projects was the design and implementation of the Intelligent Collaborative Learning System, ICLS (McManus, 1995; McManus & Aiken, 1993, 1995). Since the work we report in this paper is in part based on this system, we briefly describe this system in the context of collaborative learning systems in general.

Key components of a Collaborative Learning System include the communication interface, the student model and the group model. In this next section we discuss the communication interface and why we decided to use our particular model.

**The Communication Interface and Skills Model in Previous Work**

In order to interpret how well students are communicating (i.e. are they staying “on topic”, who is initiating ideas, who is asking questions, is everyone participating, etc.) the ICLS provided the students with menus of different sentence openers which they used to begin each of their statements. They were allowed to provide a sentence “closer” of their own choosing to complete each statement. Menus of sentence openers were chosen so as to be able to classify the type of opener the students select based upon the Collaborative Skills Model. While there are other models that could have been implemented in order to characterize the type of conversation acts being utilized, the Collaborative Skills Model with associated sentence openers proposed by Johnson and Johnson (1991) was selected (and modified) for both the ICLS and the ICSS. For example, Baker and Lund (1997) compared problem-solving behavior of students as they communicated through both a chat interface and a more
structured sentence opener interface, but studied conversation acts rather than monitoring and attempting to dynamically alter the collaborative process. Other researchers have based their analysis of collaboration on alternative models such as speech act theory (Delium, 2003), graphical user interface (Goodman et al., 2003) and dialogue games (Dimitrova et al., 2002). Constantino-Gonzalez and Suthers (2000, 2003) and Constantino-Gonzalez, Suthers & de los Santos (2003) describe how personal coaching agents in a computer-mediated learning environment can coordinate their advice to support collaboration based on shared workspaces. In addition, Barros et al. (2000) and Verdejo et al. (2002), using Activity Theory, depict how communication acts relate to effective knowledge sharing and provide guidance on activities which will improve collaboration. The Collaborative Skills Model was selected since it supports monitoring and then classification of the collaborative process.

The Collaborative Skills Model identifies four major types of collaborative skills: Communication, Trust, Leadership and Creative Conflict. These skills are further refined so that, for example, communication acts can consist of the attributes “Sending”, “Receiving” or “Acknowledgment”. Each of these attributes is represented by various sentence openers. For example, a “Sending” attribute might be indicated by the use of sentence openers such as “I think”, “Do you understand”, “I want to”, “Since”, “Tell me”, etc.

The menus presented to the student in the ICLS (& ICSS) are built using these sentence openers. In this way the system can classify every statement made by a group member as they communicate using the sentence openers. Thus, we know in real-time how many statements of each type the group members are using, whether they are initiators or responders, etc. This aspect of the system is described in more detail in a following section on the Modified Collaborative Skills Network.

The Group Leader in the ICLS

The role of a Group Leader is defined in Collaborative Learning (CL) and Computer Supported Collaborative Work (CSCW) as one who fosters a collaborative environment among the group (Johnson & Johnson, 1991), helps members assess and improve upon their collaboration (Aronson et al., 1978), monitors the members’ participation (Dubs & Hayne, 1992), provides process structure in discussions (Nunamaker et al., 1991), and directs the sequence of activities (Vogel & Nunamaker, 1990).

The functions of the Group Leader in the ICLS (McManus & Aiken, 1993) are summarized in Figure 1, categorized by the three research foundations of CL, ITS and CSCL. The CL functions are organized according to the five components proposed by Johnson and Johnson (1991); the ITS functions, by the four goals of the ICLS; and the CSCW functions by the CSCW components of the ICLS.

In experiments conducted using the ICLS students reported that they enjoyed using the system and believed that they would use such a system if it were more readily available for group work (McManus & Aiken, 1993, 1995). However, several problems were also noted which made it unlikely that the ICLS could fulfill this role. Among the problems:

- The system was very slow;
- The system was not portable to different machines;
- The system was not modular and making changes to the program was difficult;
- Inconsistencies in the classification of communication skills were noted in the log files between the beginning menu selected sentence opener and the free-form sentence closer (i.e.,
sometimes the communication was misclassified because the sentence opener chosen did not match what the student wrote in the closer), and

- Student comments indicated that there was a need to add more sentence openers, specifically those that are needed when discussing possible problem solutions.

In order to rectify these problems as well as to build a more comprehensive, flexible and portable system we designed and implemented the ICSS.

<table>
<thead>
<tr>
<th>Goals</th>
<th>Functions</th>
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<tbody>
<tr>
<td>CL:</td>
<td></td>
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<tr>
<td>Positive Interdependence</td>
<td>Enable students to develop individual projects</td>
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<td></td>
<td>Enable students to share projects</td>
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<td></td>
<td>Enable students to build group projects</td>
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<td>Face-to-face Promotive Action</td>
<td>Enable students to speak with each other and</td>
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<td></td>
<td>encourage each other</td>
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<td>Individual Accountability and Personal Responsibility</td>
<td>Enable students to evaluate each other’s project</td>
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<td>Interpersonal and Small Group Skills</td>
<td>Foster use of CL skills in discussions</td>
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<td>Group Processing</td>
<td>Enable students to assess their collaborative efforts</td>
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<tr>
<td>ITS:</td>
<td></td>
</tr>
<tr>
<td>Educational</td>
<td>Teach effective CL skills</td>
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<td></td>
<td>Tutor students in CL skills</td>
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<tr>
<td>Pedagogical</td>
<td>Monitor discussions</td>
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<td></td>
<td>Parse sentence openers</td>
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<tr>
<td>Assessment</td>
<td>Create and maintain student model</td>
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<td></td>
<td>Assess use of CL skills</td>
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<tr>
<td>Discussion</td>
<td>Enable discussion among students and GL</td>
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<td>CSCW:</td>
<td></td>
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<tr>
<td>Group Management</td>
<td></td>
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<tr>
<td>Common Database</td>
<td>Create and manage database of projects</td>
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<tr>
<td>Communication Interface</td>
<td>Enable limited natural language interface</td>
</tr>
<tr>
<td>Application</td>
<td>Enable use of editor</td>
</tr>
</tbody>
</table>

Fig.1. Group Leader Goals and Functions.
THE INTELLIGENT COLLABORATIVE SUPPORT SYSTEM (ICSS)

The Intelligent Collaborative Support System supports collaborative work by allowing students to work together in small groups across distance in a domain-independent manner (i.e. the students work on a teacher-assigned problem and the ICSS monitors and assists the collaborative effort while they work). The goal of the ICSS is to guide the group towards optimal collaboration. Modifications to previous work include an update to the interface, an expansion of the collaborative skills network, the addition of agents to search for and find keywords in the free-form closer typed in by the students, the addition of classification agents to classify the opener chosen together with keywords found, as well as agents to update the student and group models and finite state machines which model the discussions.

Modifications/Expansion of the ICLS

The basic interface of the ICSS is similar to that of the ICLS but with two key modifications: A web-based implementation, enabling collaboration over distance facilitated by a user-friendly interface; and the addition of more sentence openers, requested by students, for working on the assigned task. The Communications Interface diagram (Figure 2) depicts one of the sentence opener menus available to students using the ICSS. The sentence opener “I think”, the most often chosen selection during testing, is listed as the last opener at the end of the menu, allowing students to peruse all openers before choosing it. A long menu of choices is used for two reasons; to as closely as possible replicate the experimental conditions of the previous ICLS, and to determine which choices were most often selected so we could trim this large number of choices to a more manageable set based on the initial set of experiments. Figure 3 depicts a sample of a session between two students.

Fig. 2. Communication Interface in the ICSS.
The Modified Collaborative Skills Model implemented in the ICSS, with sentence openers and associated categories and subcategories, is based upon research by Johnson and Johnson (1991, 1999) as a methodology for categorizing and improving group collaboration by examining skills used during discussions within the group. Based upon this research, collaborative effort can be categorized by using rules to model the discussion skills necessary to promote effective collaborative learning while accomplishing the task.

As students work within their groups, they communicate with other members of the group by choosing a “sentence opener” from a menu, and then type in a free-text sentence “closer” to complete the sentence. A key component of the ICSS is that discussion skills are supported by an examination of sentence opener chosen, keywords found in the sentence closer, and the student and group models. Once found, sentence opener/keyword pairs are categorized by an intelligent categorization agent, determining the skill and sub-skill demonstrated according to the Modified Collaborative Skills Network (Figure 4).

The analysis and classification of sentence opener/keyword pairs is a crucial feature of our model since experiments using the previous system (ICLS) indicated that the system incorrectly classified group member responses because it only classified input based upon the sentence opener chosen. In reviewing the log files of ICLS interactions we found that in almost 25% of the responses the closer portion of the sentence did not correspond with the classification of the opening part chosen from the menus. For example, three consecutive interactions taken from log files contain:
Cynthia said I think Are you awake yet, or do you need some coffee?
Douglas said I think Good Morning Jeffery!!! It is too early in the morning.
Dan said I think Hello Cynthia, Sorry that I interrupted your discussion with Susan.

All three of these sentences were classified based upon the sentence opener chosen (i.e. I think) when they are actually expressing ideas that are off-topic.

Additionally, based on an examination of preliminary pre-testing results from the ICSS, and suggestions in Robertson et al. (1998), the Collaborative Skills Network has been further modified to include more “working on task” sentence openers. Students indicated in written comments that they would prefer to have a greater selection of openers that could be used while “working on the task,” i.e. while communicating with other students while performing activities that were task related. Sentence openers “I want to”, “Could we try”, “How many”, “Tell me”, “This is” and “Since” have been added to the Collaborative Skills Network as Sending sub-skills of the Communication skill based upon specific comments from students during pre-testing. Sentence openers “Let’s go on to the next question”, “How would”, “The next step should be”, “We need to” and “Don’t we have to” have also been added to the Task sub-skill of the Leadership skill also based on this feedback. Additional modifications to the Collaborative Skills Network include more “cross linking” where categorization can now be determined by the keyword used in the closer in conjunction with the opener chosen. For example, as can be seen in Figure 4, the sentence opener “I think” can be categorized as either a sending sub-skill of Communication or a Task sub-skill of Leadership. When coupled with a keyword “working” it is now categorized as a Sending sub-skill of Communication, but “I think” coupled with “good” is now categorized as a Task sub-skill of Leadership.

The Modified Collaborative Skills Network diagram in Figure 4 depicts the collaborative skills and sub-skills, modeling the discussion skills necessary to promote effective collaborative learning while accomplishing the task.
Fig. 4. The Modified Skills Network.
Fig. 4. The Modified Skills Network (continued).
ICSS ARCHITECTURE AND GROUP LEADER ALGORITHM

ICSS Architecture

Upon executing the main program, the classes defining the server representing the Group Leader (GL) create and initialize the array of student models, the finite state machines used to monitor group and individual progress and categorizations, and load the different components of the common database of knowledge; sentence openers, keywords for the closers, and the collaborative skills network for dynamic discussion categorization (Figure 5).

Upon execution, the classes that define the agents (small software classes) are instantiated, creating an instance of each agent. As students log in and work within their groups, the Group Leader module will determine keywords from the free-form sentence closers. A software agent will then attempt to categorize the sentence opener combined with these keywords from the closer.
Software agents used to perform tasks on behalf of the user are based upon a merging of research in computational intelligence (intentional systems, production systems, reasoning and neural networks), software engineering (on-line monitoring, event inference, remote actuation, image and speech processing, and distributed objects and programming) and human-computer interaction (cognitive engineering, user modeling, ITS), (Wang & Chan, 2000). Agent software can be used to perform user-delegated tasks autonomously, monitoring the environment and adjusting to events without direct intervention by the user. These agents are goal-oriented, as opposed to distributed objects, in that they cooperate to achieve their purpose, taking action when necessary to achieve their goal. In the ICSS, these actions may at times be in the form of a message to a user, a classification of a communication, or a modification to a finite state machine indicating a transition to a different state, modeling the conversation between the members of the group.

Since many of the sentence openers can be categorized as several different skills (as noted above in the discussion of the collaborative skills network), a classification agent categorizes responses using a rule-based system with forward chaining. For example, if a student chooses “This is” as an opener and “where we should place that code” as a closer, the classification agent will categorize the opener chosen together with the keyword “where” in the closer, as a “sending” sub-skill of Communication. On the other hand, if the student chooses “This is” as an opener and “how it should be done” as a closer, the classification agent will categorize the opener chosen together with the keyword “how” in the closer, as a “task” sub-skill of Leadership.

As each statement is completed by a student the agent either classifies it as a skill defined in the collaborative skills network, classifies it as one of two unacceptable classifications (off-topic or inappropriate), or classifies it as none of the above. If it is found within the collaborative skills network and classified, finite state machines for the discussion can be updated if appropriate, as well as models representing the current states of the student and the group. On the other hand if the statement is found to be off-topic or inappropriate, a communication from the Group Leader will be initiated. If the statement is classified as off-task (for example, “What do you think about ... going out to lunch now”), the Group Leader will intercede to maintain focus by redirecting the discussion in a subject-specific manner. Inappropriate statements (for example, “I agree, but ...” and “That’s good, but ...”) are handled in the same manner, but without subject-specific responses. These statements are actually an attempt to communicate two or more different ideas in the same statement (for example, a communication skill and a creative conflict skill within the same sentence). For example, the following is taken from ICLS log files:

Justin said I think it won’t affect the difference that is put into the equation but I believe an if statement is necessary in order to find a percentage which is above the mean – thank you for your comments neighbor.

This statement actually expresses three separate ideas. The Group Leader recognizes this due to the key words “but” and “thank you”. The sentence (segment) using the sentence opener “I think” before the keyword “but” is recognized as a unique statement by the agent; the segment beginning “I believe” is recognized as a second, separate thought once the sentence opener “Thank you” is encountered and this opener then signals the third segment (“thank you for your comments neighbor”). Since the use of the collaborative skill of communication is improved when each statement expresses only one idea (Johnson & Johnson, 1991), the Group Leader will then send a message asking the student to express ideas one at a time.
After classification of each sentence, an agent will then update the group model (represented as the push-down automata for each group) and the appropriate student model for individuals within each group. The student model, illustrated above in Figure 6, will be incremented as well as the total number of statements for the student and the group. Additionally, the student and the group models will be reclassified by a classification agent to evaluate how well the student is working within the group and whether the group model is affected by this re-evaluation.

A transition in the group model finite state machine (FSM) to a state representative of a more productive group might be made when all students have made no off-topic statements, for example within the most recent 30 statements. The state can change negatively (representing a less productive group) by examining the frequency of either statements ignored or unacceptable statements, for example within the most recent 90 statements (assuming at least some were also in the last 30). This would be indicative of a pseudo or traditional group (those statements demonstrating a lack of interest in working together). An examination of the frequency of total responses made by each student can also trigger a negative transition if the frequency for one student drops, for example, below 20% for the most recent 90 statements, indicating a student who is not participating equally and demonstrating a lack of individual accountability. These negative transitions trigger the second type of Group Leader communication in response to individual or group categorization.

A tally also maintained in the Group Model is examined by an agent to determine if the group discussion enters into a discussion loop where students continue to choose statements indicative of disagreement. When this tally reaches an upper limit, a priori set to 10 iterations through the loop, the Group Leader will intercede with a statement to the group to suggest a re-evaluation and compromise or mediation, and then jump to a creative conflict FSM to further monitor the discussion.

To incorporate the use of creative conflict (where group members are working to resolve a disagreement) as an instructional tool, pedagogical expertise of the GL is embedded in a creative conflict finite state machine (FSM) and a FSM traversal agent serves as a “mediator” to assist in formulating a constructive discussion. The creative conflict FSM models transitions from an initial display state through confirm/disconfirm states and then either converges or receives a request for human mediation (Roschelle, 1992). Sentence openers are regrouped into sets modeling the discussion.
as students resolve conflict, and Group Leader responses encourage compromise. It is possible for the discussion to once again enter a loop while traversing the creative conflict finite state machine, at which time the Group Leader will intervene with a suggestion for communication with a human teacher.

One aspect of the Skills Network that we plan to study further is this Creative Conflict component. As we, and other researchers have noted (for example, Tedesco 2002, 2003), creative conflict can assist students to more carefully reason and support their arguments. In fact, “If well employed, conflicts can trigger cognitive changes” (Tedesco, 2002, p. 619). It will be interesting to explore what types of creative conflict lead to “deadlocks” and which types result in reasoned arguments to which all participants agree.

**Group Leader Algorithm**

The Group Leader module monitors and guides the interaction of students towards a more highly collaborative group as described in collaborative research by Johnson and Johnson (1991, 1999). The module accepts data from the students as they work within their groups, and then sends it to agents for classification, logging and updating of the finite state machines and models. The Group Leader will then use message passing to communicate with the group and with individual students within the group. Communication from the Group Leader is initiated on two levels: in response to sentence opener/keyword statements and in response to individual and/or group categorization.

The Group Leader additionally helps guide students to a more “balanced” collaboration, thus encouraging a more even distribution of comments from members of a group rather than one person dominating the discussion. For example, one transcript indicated that a student had not been participating in the discussion for several statements and her frequency of participation (FOP) became 6%. The Group Leader then sent a message to the group reminding them that everyone should participate in the discussion.

In the ICLS, categorization was based solely on the sentence opener chosen for each statement, but a survey of the log files developed during testing showed a large number of free-form sentence closers that did not match with the opener chosen. Many statements were therefore incorrectly categorized by examining only the sentence opener (McManus, 1995). To achieve a more reliable classification, keywords found in the sentence closer are coupled with the opener before being sent to a classification agent.

Analysis of transcripts of sessions from the ICLS of McManus shows students often selected inappropriate sentence openers, perhaps because there were no appropriate ones to handle the statement at hand, a fact supported by Robertson, Good and Pain (1998), and Soller, Goodman, Linton and Gaimari (1998). More recently, Soller (2001, 2004) found that the sentence opener matched the intended attributes in only 68% of the conversation, unless the set of sentence openers was adjusted to account for differences between face-to-face interaction and collaborative online interaction. Classification based upon keywords found in the sentence closer taken together with the opener chosen addresses this issue. In a second series of experiments done by the authors (reported below) where this technique was employed, results indicated that the responses were correctly classified 100% of the time when a keyword was recognized, but keywords were not recognized in 30% of responses. With each new set of experiments we discover additional keywords to add to the rule base. Thus, in the future we expect to significantly reduce the number of unrecognized responses.
**Group Leader Pedagogical Expertise**

The pedagogical expertise of the Group Leader is embedded in two finite state machines for each group; one representing discussions and the second, creative conflict, as well as the heuristics for the FSM traversal agent (Figure 7 shows the Discussion FSM). We use the following notation: Nodes of the FSM are labeled by type and number; Nodes labeled as “I” denote an interaction with the GL, those labeled “D” represent a Displaying state, “C” a Confirming state, “DC” a Disconfirming state, and nodes labeled with concentric circles, a Final or Convergent state. Each sentence opener has an associated number (as shown in Figure 4). They are grouped into pre-determined sets representing the set of sentence openers that are valid for transitioning from one specific state to another (as suggested in Johnson and Johnson (1991, 1999)). Edges are labeled with a set x of sentence openers, using any of which will cause a change of state when activated. For example, set #5 consists of sentence openers 1-13, 19-24, and 29, while set #6 consists of sentence openers 14-18, and 24-26.

*If the sentence opener selected, together with keyword found in the closer, is categorized as valid, a modification to the discussion FSM will occur.* For example, if the current discussion is represented by state DC-4, choosing a sentence opener from set #6 would cause a transition to state F-7, a final state representing an end to the current thread of discussion. Thus, the sentence openers selected, when used with a valid keyword in the closer, are the indicators to move from state to state.

As discussions proceed, agents monitor transitions through the various FSMS for each group. These agents interact with the Group Leader, which will communicate with the group if there seems to be a problem. For example, a loop in the traversal of a FSM would signify a lack of progress within a discussion so the GL would interrupt and provide a message to try and get the group members to agree on a position that would get them re-focused and converging on a possible solution path.

Since different finite state machines are used to model discussions and creative conflict, it is possible to associate each finite state machine with different sets of sentence openers. This allows the Group Leader to monitor and respond to creative conflict discussion in a context-sensitive manner (suggesting compromise, for example). These sentence openers can be found in the Creative Conflict portion of the Modified Skills Network in Figure 4. The list of all the sets of sentence openers associated with both a discussion FSM traversal and a creative conflict FSM traversal can be found in Appendix A as well as Israel (2003). The finite state machines are represented internally as adjacency lists.

A modification in the FSM traversal is considered when the agent categorizes the opener/keyword pair as valid and acceptable. As the GL receives data representing sentence categorization from the agent, transitions reflecting this data are made in the FSM for the current discussion using the generalized transition function \( f(s_i, i) = s_j \) where \( s_i \) is the current state, i is the sentence opener, and \( s_j \) is the next state. The finite state machines, reflecting Roschelle’s process-oriented theory of collaboration through convergence based upon sentence phrases (Roschelle, 1992), mark iterative transitions from an initial display state (Phase 1, where a student explains a topic to others) through states representing confirm or disconfirm (Phase 2, where a student agrees or disagrees with the explanation previously given) and then states representing repair until convergence (Phase 3, where students interact to correct a misunderstanding or incorrect statement).

When the sentence opener is either paired with an inappropriate keyword or no keyword (if one is necessary), pedagogical expertise is embedded in GL methods that generate appropriate feedback and control since there is no classification possible. If the sentence opener is coupled with a keyword found within a group of off-task closers (i.e. I think we should go to lunch ...), the GL displays a
message to the student requesting more appropriate dialogue and will use a counter to tally the number of such occurrences. If the sentence opener is coupled with a keyword found within a group of inappropriate closers (i.e. I agree, but ...), the GL displays a message requesting a more appropriate sentence opener for the statement and once again a tally is updated.

Fig. 7. Discussion Finite State Machine.
STUDENT MODEL

For each student a student model, reflecting a current representation of the student’s participation, is maintained by the Group Leader. This data structure (shown in Figure 8) includes an array of counters to tally usage of each skill categorized by the agent and represented in the Collaborative Skills Network, to be used in determining the type of student participation within the group, as well as a tally of inappropriate and off-topic statements. Other data maintained include a ratio representative of the frequency of interaction of this student in relation to total interactions, which is used to determine the amount of student participation within the group. Also general bookkeeping information is maintained, such as student name and group membership. Note that each sentence opener, when paired with a “valid” keyword from the closer, will be classified as a single skill. Thus, only one counter (C0, C1, C2 or C3) will be incremented, so the counters are mutually exclusive. Note also that C0, C1, C2, and C3 are independent from both C4 and C5 since they count different types of valid sentences (those that can be classified) whereas C4 and C5 are counters for non-valid sentences. Also, C0, C1, C2 and C3 are not mutually exclusive with C6 in that the use of a communication skill, for example, could also be considered as initiating an idea.

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<thead>
<tr>
<th>STUDENT MODEL (refer to Figure 4 for Sentence Openers)</th>
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<tbody>
<tr>
<td>Communication Skills Counter</td>
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<td>Trust Skills Counter</td>
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<td>Leadership Skills Counter</td>
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<td>Creative Conflict Skills Counter</td>
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<td>Off-Topic Opener Counter</td>
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<tr>
<td>Inappropriate Opener Counter</td>
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<td>Initiating Ideas Counter</td>
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<tr>
<td>Frequency of Participation</td>
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<tr>
<td>Bookkeeping</td>
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<td>Agent Classification</td>
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Fig.8. The Student Model.

An agent categorizes each student based upon an analysis of 1) Promotive Interaction, 2) Social Skills and Group Processing, and 3) Positive Interdependence and Individual/Group Accountability (Johnson & Johnson, 1999). Justifying opinions (the use of opener/keyword statements categorized as Structuring Controversy), initiating ideas (the use of statements categorized as Leadership), and asking questions of peers (Leadership/Structuring Controversy) are all skills indicative of students functioning well within a collaborative group. Structuring Controversy (for example, “The advantages of this idea are ...”) and Leadership/Task openers/keywords demonstrate positive interdependence (Johnson & Johnson, 1999) where members are committed to maximizing each other’s learning. This method of building the student model therefore tallies the use of each of these skills, but unlike that employed in a traditional ITS, does not attempt to determine how the students came to their decisions.

Modifications to the student model are based upon an evaluation of three components:

1. the frequency of occurrence of each category/skill;
2. the frequency of occurrence of those sentence opener/keyword pairs indicative of a cooperative learning group with positive interdependence (Johnson & Johnson, 1999);
3. the selection of sentence openers falling within categories of effective written and spoken discussions (Robertson, Good, & Pain, 1998; Harwood, 1995) of initiating ideas about a topic (Initiating/Responding), following the existing focus of a conversation (Following/Changing), justifying opinions (With Reason/Without Reason), questioning other group members (Questions/Statements), and keeping the conversation on task (Off task/On task).

These categories are not mutually exclusive (the same opener/keyword can be considered to be “Following” the focus if it is continuing a conversation, and also “Initiating” if it states an opinion for the first time within that focus).

The agent returns with an evaluation $S_i$ of the student’s collaborative effort using the function $f(x_i, y_i, z_i) = S_i$ and the counters in the student model shown in Figure 8, where:

- $x$ represents a ratio indicative of the use of promotive interaction, positive interdependence and accountability (i.e. responses where the sentence openers and closers match, where students are working on task and providing each other with the help and support necessary for both academic and personal growth, encouraging and bringing into focus a discussion of the group process) (Johnson & Johnson, 1991, 1999), computed as:

$$x_i = \left(\frac{C_0_i + C_1_i + C_2_i + C_3_i}{\text{total number of responses from student } i}\right);$$

- $y$ represents the ratio of initiating / responding, indicative of initiating ideas and assuming personal responsibility:

$$y_i = C_6_i / \left(\text{total number of responses from student } i\right);$$

- $z$ represents the ratio indicative of working together on task with effective discussions:

$$z_i = C_0_i / \left(\text{total number of responses from student } i\right);$$

Feedback based on this information is provided to the students when they quit the session, indicating how effectively they collaborated and encouraging reflection and self-assessment.

**GROUP MODEL**

The Group Model is implemented as a push-down automata (PDA). The flexibility of the PDA allows for the representation of a finite state machine with external memory implemented as a stack. This implementation includes a finite state machine to represent the current state of the group along with a stack to hold tallies and frequencies of the usage of sentence openers. The GL will then examine the stack of tallies dynamically before changing the state of the group represented in the group model finite state machine.

The group model shown above contains not only a finite state machine to model the current discussion but also contains a stack to hold tallies for total responses for the group, total inappropriate and off-task statements, and a tally to monitor the occurrence of a loop. Frequencies of the usage of off-topic and ignored statements are also computed and stored in the stack. The tallies and frequencies are then examined by the Group Leader dynamically as discussions progress, and may trigger an interaction between the Group Leader and the group of students. For example, if $R1$ becomes greater than .25 (indicating that students are maintaining a discussion that is off-topic), the GL will broadcast a statement to each member of the group (“Please try to stay on-topic while working with your
The ratios $R_3$, $R_4$ and $R_5$ are used by the GL to indicate when a student’s level of participation is low or too high (indicating that the student is tending to dominate the discussion). The use of these tallies and frequencies is further explained below.

**Fig.9. The Group Model.**

The group model (shown in Figure 9) is coded as a connected pseudo-graph (an undirected graph with the property that there is a path between every pair of vertices in the graph, with the possibility of cycles and loops) containing 28 nodes. Assuming there are three students per group, a modification of the group model finite state machine occurs using the transition function $f(s_i, Q) = s_j$ where $s_i$ is the current state, $s_j$ is the next state, and $Q$ is a triple $(q_1, q_2, q_3)$ (Note that the “t” and “q” values are “group” measures since these values represent the arithmetic mean of the three students in the group):

- $t_1$: average $(x_1, x_2, x_3)$ where $x_i$ = the $x$ values for each student as explained previously in the section on the student model
- $t_2$: average $(y_1, y_2, y_3)$ where $y_i$ = the $y$ values for each student
- $t_3$: average $(z_1, z_2, z_3)$ where $z_i$ = the $z$ values for each student

- $q_1$ = Low if $0.0 \leq t_1 \leq 0.3$
- Med if $0.3 < t_1 < 0.7$
- High if $0.7 \leq t_1 \leq 1.0
q₂ =  
- Low if 0.0 <= t₂ <= 0.1
- Med if 0.1 < t₂ <= 0.4 or 0.7 < t₂ <= 1.0
- High if 0.4 < t₂ <= 0.7

q₃ =  
- Low if 0.0 <= t₃ <= 0.24
- Med if 0.7 < t₃ <= 1.0
- High if 0.24 < t₃ <= 0.7

The combinations of the three possible values for q₁, three possible values q₂ and three possible values q₃ are represented in a finite state machine with 27 nodes plus an initial node.

Since the frequency of occurrence of each category/skill will change dynamically as students work, an evaluation of the group will occur as frequencies fall within a range of values. For example, the value of q₁ is categorized high when in the range 0.7 ≤ q₁ ≤ 1.0; the value of q₂, the ratio of initiating/responding and assuming personal responsibility is categorized high when in the range 0.4 ≤ q₂ ≤ 0.7; the value q₃ is rated high when in the range 0.24 < q₃ ≤ 0.7. These ranges have been established a priori based upon an analysis from the initial trials and results reported in Robertson, et al. (1998) and will be modified as more data are collected. Note that the value of q₂ is determined to fall in the medium range when either 0.1 < t₂ ≤ 0.4 (indicating that the student is not participating fully) or 0.8 < t₂ ≤ 1.0 (indicating that the student is tending to dominate the discussion). The values associated with each range of q₂ are therefore:

- high if falling between 0.4 and 0.8;
- medium if greater than 0.1 and less than 0.4 (the students initiate slightly less than 0.4);
- medium if greater than 0.7 and less that 1.0 (the students initiate slightly more than the high range);
- low if less than 0.1 (students hardly ever initiate).

Note also that the value of q₃ is determined to fall in the high range when 0.24 < q₃ ≤ 0.7, since a higher value would indicate task work with little or no leadership, trust or creative conflict resolution.

The values associated with each range of q₃ are therefore:

- high if falling between 0.25 and 0.7;
- medium if greater than 0.7 and less than 1.0 (the students work almost exclusively on task with very little leadership, trust or creative conflict resolution);
- low if less than 0.25 (students spend less time working on task).

As an example, suppose a snapshot of student #1 (S1) reveals (refer to Figure 8 above):

<table>
<thead>
<tr>
<th>C0</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>F0</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>0.4286</td>
</tr>
</tbody>
</table>

Suppose student #1 completed a total of 30 responses (including some ignored responses). Then S1 can be represented as (x₁, y₁, z₁) = (19/30, 3/30, 12/19) = (0.633, 0.1, 0.631). We would then have a similar triple for S2 = (x₂, y₂, z₂) and S3 = (x₃, y₃, z₃). A snapshot of the group model at this point might reveal:
• \( t_1 = \text{average}(x_1, x_2, x_3) = 0.45; \)
• \( t_2 = \text{average}(y_1, y_2, y_3) = 0.09; \)
• \( t_3 = \text{average}(z_1, z_2, z_3) = 0.75, \text{ thus} \)
  • \( q_1 = M(\text{ed}); \)
  • \( q_2 = L(\text{ow}); \)
  • \( q_3 = M(\text{ed}). \)

A transition to this new assessment of the group’s collaborative activity, MLM (from MLL, for example) would be made. Note that since there is no change in the value of the first parameter (M), this indicates that the group’s use of promotive interaction, positive interdependence and accountability remains at the same level. This is also true for the second value (which retains an “L” categorization) indicating that the assessment of the group’s activity in initiating ideas and assuming personal responsibility has also not changed. However, the third parameter, measuring the effectiveness of the group’s working on task, improved from “L” to “M” indicating a positive change in this type of activity. The GL will inspect this new state and if indicated, a comment would then either be sent to the student or sent to the group.

The students are not aware of the group or student model as they work within their groups. Group processing is reified when the group members reflect and assess the effectiveness of the collaborative process (Johnson & Johnson, 1999). This is implemented when students quit the discussion (session) by pressing the “Quit Session” button. Once this button is pressed, students are presented with a copy of their own and their group’s model (such as HLH), allowing them to assess the cumulative effect of their communications with the other members of the group, as well as their own collaborative skill level as determined by the Group Leader.

**EVALUATION OF THE ICSS**

The focus of this research is the design of an Intelligent Collaborative Support System (ICSS) to support students working synchronously in different locations using a web-based interface. The evaluation of the ICSS utilized a mixed form of evaluation design, in two separate studies.

**The First Study**

This preliminary study allowed us to debug the system and evaluate the performance of the ICSS along two dimensions:

• assessing how well the ICSS performed technically (i.e. extent of software problems, perception of system interference/facilitation in student communication, etc.) and
• evaluating how effectively the system aided students in their efforts to collaborate to solve a problem.

Data were gathered through the use of pre and post-questionnaires, a log file kept for each student and group, and discussions with students after the experiment was completed.
Subjects

The subjects in this study were 55 undergraduate students enrolled in an introductory computer science course working on programming assignments using the “C” programming language, as well as students enrolled in more advanced Computer Science courses in Operating Systems. The students volunteered to participate in the study and neither received pay nor extra credit. These courses were chosen because they offer a cross-section of students taking Computer Science courses. Twenty-eight of the students enrolled in the courses were Computer Science majors, nineteen were Computer Information Science majors, four were dual Mathematics Education and Computer Science majors, two were Liberal Arts majors, and two were undeclared. There were 46 males and 9 females. Ages ranged from 19 to 23.

Procedure

The testing environment was a computer lab containing 25 dual boot PCs (both Linux and Windows 98) with one student per station. Students tested the ICSS in three separate sessions, with 18 students in the first session, 21 in the second, and 16 in the third. All the students worked on the same assignment. In all three sessions, the ICSS server software was used, and then students used Netscape 4.7 in the Windows 98 environment to access the software web page. After entering a login name, students were assigned to groups by the Group Leader software module and worked together for 40 - 45 minutes on the assignment (Appendix B – Experiment 1).

Measurement of the students’ perceptions of the ICSS were documented using a pre-questionnaire and a post-questionnaire containing multiple choice, T/F, and free response questions (Appendix C).

Observations of the subjects were done both by a human teacher and by the ICSS, with the accumulation of raw data in session log files and aggregate data included in the student model for each student, and the group model.

Results

Results gathered from student questionnaires were useful for evaluating the efficacy of the system, assessing to what extent students collaborated in solving the problem, and learning what they thought of this experience. In general, students felt the system helpful and easy to learn, and indicated that the system helped their group focus on discussing the problem and arrive at a solution. Several suggestions given by students in the free-form suggestion area of the post questionnaire have already been implemented. These include adding more sentences openers for the sending sub-skill and for the creative conflict discussions. Some of the highlights from this preliminary study include the following Israel (2003):

- 65% of the students responded that the ICSS was effective in helping the group solve the problem and contributed to a productive group project. Students indicated satisfaction with the system and found it to be a useful tool for collaboration. Students willing to work in groups were more satisfied with the system and found it more useful than students with negative attitudes towards working in groups;
• Students indicated that they benefited from working with others even if they were working asynchronously and found that this helped them to develop novel solutions to problems. 89% indicated that the web browser interface was effective for discussions with other students. This interface allowed students to work with other students in their group without awareness of the location of those students;
• Of the 55 students who tested the system, 41 replied they would use the system again when working on a group assignment and would use it to collaborate on other problems. 80% of the students responded stating that the system was fair or better than working on a group assignment without the system, with 40% of the students responding that the system was good or excellent, another indication that they would use it in the future;
• Of interest is the amount of interaction with the Group Leader that students perceive. Of the 55 students completing the questionnaires, 30 stated that the system did not interfere with group work, versus 25 who felt that the system sometimes interfered. Students felt that the system, embodied in the Group Leader, responded in a timely fashion with clarity and appropriateness;
• Additionally, the majority of students said the group functioned well, with no one student dominating the discussion and no feeling of intimidation by other members of the group.

The Second Study

This study looked at the performance of the ICSS after improvements were made based on comments from students in the first experiment. In this study there was an increased emphasis on collecting quantitative data that would assist us in tracking the dynamic classification of the group. In addition to making several system changes (such as adding new keywords for the closing portion of the sentence), the log files were modified for both the student and group models in order to provide a more clearly defined path for identifying the modification of the group’s classification over time (e.g. LMH to MMH) as students worked on an assignment (Appendix B – Experiment 2).

Subjects

The subjects in this study were 37 undergraduate students enrolled in a third semester required computer science course working on programming assignments using the Java programming language, as well as students enrolled in a more advanced required Computer Science course in Operating Systems. Twenty-three of the students enrolled in the courses were Computer Science majors, and fourteen were Computer Information Science majors. There were 35 males and 2 females. Ages ranged from 19 to 24.

Procedure

Evaluation of the performance of the ICSS primarily involved an analysis of log files recorded during student sessions. These log files contained, for each student and each group, raw data of sentence openers together with typed closers, keywords found within the closers (or an indication where none was found), categorization for each statement made by each student, and finite state machine modifications showing when (and how) a change was made in the groups’ solution path. Aggregate
data also included the student model for each student, and the group model after each statement was classified.

Additionally, students were asked to collect a list of sentence openers that they felt might be added at a future time to support working on task, and these lists were collected after the experiment.

The testing environment was a computer lab containing 25 dual boot PCs (both Linux and Windows XP) with one student per station, and testing was done in two sessions to accommodate the 37 students (23 students in the first session, assigned by the Group Leader into 8 groups, and 14 students in the second session, assigned by the Group Leader into 5 groups). The ICSS server software was executed by the teacher, and then students used Internet Explorer in the Windows XP environment to visit the ICSS web page. After entering a login name, students were assigned to groups by the Group Leader, and worked for approximately 30 minutes on the assignment. Observation of the subjects was done both by a teacher and by the ICSS, with the dynamic accumulation of data stored in dated session log files.

**Results**

Results gathered from an analysis of log files for the 13 groups are summarized in Table 1 below. Note that these categorizations are not listed in any particular order in the table (each possible categorization is listed, but the order is arbitrary) but are rather summarized here to illustrate how groups were dynamically categorized as their discussions progressed. Some of the categories (e.g. HMH, MHL, etc.) have no entries in the “State Transitions” column since none of the 13 groups passed through these classifications during the various stages of their collaborations. [Note that “H” (High), “M” (Medium) and “L” (Low) are used to assess the group’s collaboration level based on the following three parameters: First, Promotive Interaction; second, Social Skills and Group Processing; and third, Positive Interdependence and Individual/Group Accountability, as discussed in the Student Model section. Therefore a category of HMH would indicate that the group evaluated to H(igh) in Promotive Interaction, M(edium) in Social Skills and Group Processing and H(igh) in Positive Interdependence and Individual/Group Accountability.]

For example, Group # 6 went through the following transitions from the beginning until they finished their discussions \{LLL, LLH, MLL, MLH, HLH\}. One of the items we want to examine in future studies is whether some of the states that were not reached by any of these groups (such as HMH or HMM) are reached by other groups, and whether there are some interesting patterns among the state transitions that should be explored.

The log files capture the groups’ discussions as students proceed to solve the problem. Below is a sample showing the input text, as well as how it is classified, when one of the students begins the discussion in their group:

```
  toni: How would we start?
  ..keyword: start
  ..category: Task: Leadership
  ..skill: Leadership
  ..sub-skill: Task
  ..Current State: 1
  ..group state: MLL
```
Table 1

Testing Results (Test 2)

<table>
<thead>
<tr>
<th>Total Number of State Transitions (by classification)</th>
<th># groups</th>
<th>Final categorization</th>
</tr>
</thead>
<tbody>
<tr>
<td>HHH</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>HHM</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>HHL</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>HMH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HMM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HML</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HLH</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>HLM</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>HLL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MHH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MHM</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>MHL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MMH</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>MMM</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>MML</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>MLH</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>MLM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MLL</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>LHH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LHM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LHL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LMH</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>LMM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LML</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>LLH</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>LLM</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>LLL</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

In this case, the sentence was correctly categorized as a Task sub-skill of a Leadership skill. For this student the student model was recorded as \(x1=1\), \(y1=1\) and \(z1=0\). Since sentence opener 23 was chosen, the Communication Skills Counter, C0, which uses Sentence Openers 1-17 was not incremented, thus \(z1=0\) since C0=0. Since this was only the first sentence entered, the other students had no interaction and therefore their student models contain the values, \(x2=0\), \(y2=0\), \(z2=0\) and \(x3=0\), \(y3=0\), \(z3=0\). The group model, which maintains an average of the interaction for all three students, was computed as \((0.333, 0.333, 0)\) and the group was evaluated as MLL based on the classification scheme of the Group Model discussed previously.

Table 1 summarizes the tracing of the dynamic classification of the group models by the ICSS as the groups worked through the problem. Eleven of the 13 groups became high performing (i.e., all three parameters for the group are “H”) at some point. In addition, all the groups also became less productive at some point (for example by changing to a MLL, LML, LLM or LLL group model from a higher performing classification). This was sometimes caused by at least one of the members using an unclassified sentence closer. In those cases where a group’s performance dropped dramatically there
was evidence of “off topic” conversations, such as discussing when and where to have lunch. Three groups became HHH after having a group model that was considerably lower. In each case the group members responded to the Group Leader’s comment to “Please keep on topic”. All group models that initially evaluated to LLL eventually became at least MLL when they maintained a topic of discussion. For example, one student working in a group evaluated at LLL wrote “Could we try to enter a zero?” The system used “Could we try” (sentence opener 9) with the keyword “enter” to categorize this as a Sending sub-skill of Communication. Since the student used an appropriate sentence opener for working on task, the $x_i$ for this student increased, the $t_i$ for the group increased, and the value of $q_1$ fell within the range $0.3 < t_1 < 0.7$ and thus was classified as M(ed) (see above discussion on the Group Model). This modification of the Group Model demonstrates that it is possible for a single appropriate statement to cause a modification to the Group Model classification, especially early in the discussion when the total number of responses is low.

The second column of Table 1 provides a summary of how the different groups were classified at the end of the experiment. Many groups lost focus as the discussion converged on a solution, as evidenced by classifications containing a “M” or “L”. These groups, as their discussions were concluding, had more sentences where either keywords were not found or unacceptable keywords were found, resulting in a lower classification. Snapshots of two of the logs are shown in Appendix D as Samples 1 and 2. Several points stood out as we reviewed the data and attempted to determine how to make the ICSS a better tool for collaboration:

- The amount of interaction with the Group Leader that students receive, and how they perceive this interaction is not always consistent. When groups achieved the classification of HHH (high performing) there were very few comments from the GL module to the students since they did not need the GL to intervene, while groups categorized as MMM or lower all had some feedback from the GL at some stage during their session. From Study 1 we found that the majority of students felt that the system did not interfere with group work. However, Data from the log files suggest that although students do not necessarily perceive that such interruptions are a problem, in fact they do serve as a distraction. This was especially the case for those who are having difficulties collaborating as indicated by a “M” or “L” classification;
- Group Leader interactions found in the log files mainly concerned the use of an inappropriate keyword (for example, I agree, but… where the word “but” indicates that a sentence closer will not be correlated with the sentence opener) or a notation that too many sentences had occurred without keywords being found;
- There is a need to increase the number of keywords recognized. Many sentences can obviously be recognized as working on task upon review of the log files, but were not recognized dynamically by the system. Thus the group was inaccurately categorized as a lower performing group; in a few cases even LLL. These additional keywords will be added to rules, making the system more robust for future testing;
- There was a significant improvement in the classification of those sentences where a keyword was found in the closer compared to the previous studies that did not consider the closer when classifying. However, we were surprised to find that the classification of the sentence correctly matched the intended attributes in all cases. Thus, using this new classification model we significantly improved over the results in our previous experiment and the 68% correct matching reported in Soller, (2001). In this improved classification scheme sentence openers paired with inappropriate words in the free form closing part were not classified as a valid use of a skill. Moreover, these “invalid” sentences were further classified into categories
that allowed the Group Leader to provide feedback appropriate to the response used. This confirmed our hypothesis that matching sentence closers with sentence openers would provide a more accurate representation of a group’s collaborative skills than previous studies where such techniques were not employed;

- An examination of log files suggests that as discussions within the group continue, the group model becomes less descriptive, i.e. modifications to the group model become less dynamic with each new sentence classified. As additional sentences are classified, each sentence opener has less of an effect upon the percentage of total sentence openers used, and therefore modifications to the group model occur more slowly. Thus, there is a need to address this issue in the future, perhaps by reinitializing the group model as discussions converge, or increasing the weight of later responses when recalculating the group model; and

- An examination of log files also shows that after receiving Group Leader feedback, all groups refocused on the problem, suggesting that the students were more “on-task” and collaborated more effectively using the ICSS. (See Appendix D for two examples from the log files indicating when the GL intervened and how students responded to the GL comments.)

In the free response section of the questionnaire several students suggested adding sentence openers such as “Did you”, “Can you”, “I don’t know”, “I don’t agree”. They indicated that they felt the system would be more flexible if these openers were available.

It is interesting to note that sometimes students attempted to engage the Group Leader in discussion rather than work with other group members to solve the problem. Some students noted the comments returned by the Group Leader when they entered inappropriate sentences, then attempted to find the limit of the “knowledge” encoded in the classification agent. Of course this led to their being classified in a “lesser performing” category, but that was not their primary goal. However, these students were helpful since we can use the recording of these inappropriate keywords for future encoding as rules for the agent. In addition, these interactions were useful for determining how well the Group Leader responded. Future experiments might include a modification to the Group Leader algorithm to ignore these statements - with a study to compare outcomes with and without Group Leader responses to inappropriate statements.

**CONCLUSIONS AND FUTURE RESEARCH**

We believe that just as our students need to improve their communication skills so do they need to improve the way they work in groups. As noted in Kiesler and Hinds, (2002) technological advances in conjunction with changes in the global economy are increasing the geographic distribution of work in industries as diverse as banking, wine production, and clothing design. Work teams are spread across different cities or countries while their projects involve work in many locations. For example, the electronic community that created the original Linux computer operating system would suggest that distributed work arrangements can and should be flexible and innovative. At the same time, distributed work complicates workers’ professional and personal lives. Distributed work alters how people communicate and how they organize themselves and their work. Support for this distributed process is becoming increasingly important.

This research develops an Intelligent Collaborative Support System (ICSS) that supports a collaborative effort by analyzing and modifying the collaborative process dynamically. Its goal of
getting people to work more effectively together is accomplished when groups are categorized and guided toward the optimal category of a high-performing cooperative group with positive interdependence. The use of the dialogue designated as creative conflict is mediated by an agent to assist in formulating a constructive discussion; one that serves as an instructional tool. Conflicts in the categorization of discussion skills exhibited in the sentence openers vs. skills exhibited in keywords found in the sentence closers are resolved before classification. Implemented in Java and accessed via a familiar web interface, students work in groups remotely in the cross-platform environment provided by the Java Virtual Machine. Results of qualitative experimental research show that students were satisfied with the system, thought it was useful, and would use it again for future collaboration. Additional testing indicates that the system is useful for categorizing groups dynamically and for guiding students to work more effectively, as shown by a modification of the group model from a less productive category to a more productive category as students work.

Several agents interact with the Group Leader, performing services on behalf of the system. As students collaborate within their groups, an agent categorizes each statement using a rule-based system with forward chaining. Other agents are employed to monitor and mediate discussions and creative conflict. Agent classes can be easily modified for later enhancement or experimentation, and new agents can be created by instantiating the agent class.

Based upon the classification returned from the agent, the Group Leader updates the group model (represented as the push-down automata for each group) and the student model for individuals within each group, and will respond to both students and the group based upon these models. Students can later reflect and assess the effectiveness of the collaborative process when they quit the session, as the group and student model are displayed for each student.

The ICSS contributes to the broader field of collaborative learning by helping students focus on the topic at hand while encouraging all students to participate in the discussion. Individual students feel free to contribute ideas, and groups are encouraged to converge upon a solution. Because students use a web interface to communicate with members of their group, they can collaborate with other students logistically in the same place or not, using a common application and sharing a common database.

Other areas for future research could include:

- Modifying the list of sentence openers presented when a student is frequently presenting off-topic or unacceptable statements (presenting fewer sentence openers, or presenting sentence openers in a different order, so that students can better focus on the topic at hand);
- Modifying the list of sentence openers presented when the group is categorized as traditional or as a pseudo-group (presenting fewer sentence openers or presenting sentence openers in a different order, to guide the group toward the optimal category of a high-performing cooperative group with positive interdependence);
- Adding a component with machine learning to find and classify additional keywords dynamically (so that as more students work using the ICSS, more keywords will be recognized and correctly categorized, making the ICSS more robust);
- Evaluating and incorporating $S_t$ for each student in addition to the currently implemented evaluation of the group (i.e. evaluating each student as $H$, $M$, or $L$ based upon their participation within the group). This would then lead to an evaluation of individual student participation, with a modification of the student model to include a finite state machine. This is related to the research reported by Muhlenbrock et al. (1998) who developed a framework for work within an Open Distributed Learning Environment, including a design for multi-user
environments, intelligent learning support, and a multi-agent paradigm for multiple student modeling;

- Incorporating a cooperative learning model (e.g. the Jigsaw method), enabling a quantitative analysis of the ICSS based upon domain knowledge gained as a result of the collaborative process;
- Examining the collaborative success of the student based upon membership in a particular group, as related to the perceived success of the other members of the group (i.e. does membership in a particular group affect success with the ICSS?);
- Adding an agent that asks the student to enlist the aid of the teacher when encountering a creative conflict cycle or when a finite state machine reaches a flagged state, creating a “Hybrid” or “Blended” system capable of addressing these events;
- Modifying the message-passing so that students can continue discussions after logging out and then logging back in later. Presently, each user including the server, is named consecutively as peer0, peer1, etc., without designation as to group membership. A modification to this naming structure would also include the addition of a hash structure to quickly find and continue the most recent thread of discussion; and
- Following the students while they communicate with each other to see what interactions attract their attention and motivate them. This is related to the research being conducted by both W. L. Johnson and his group, where they use eye-tracking software to follow users’ focus of attention (cf. Qu et al., 2004), and C. Conati and her collaborators, where eye tracking can help assess mental states underlying a given behavior, (Conati et al., 2005 and Merten & Conati, 2006). This could provide another indicator as to which students were being more reflective in their responses and which were simply “playing a game”.

In addition, the ICSS can be used as a platform for other types of experimentation. For example, a colleague at the University of Pau has developed a new system, EVACOLEN (Evaluation de la collaboration en ligne), by integrating the Tulka Whiteboard with the ICSS. The goal is to assess whether students who collaborate more effectively using the ICSS are also more productive in solving different types of problems using the whiteboard. Results from some preliminary testing indicate that the students who collaborate more effectively also are more effective at solving the problem. Additional information can be found in (Bessagnet et al., 2004; Aiken et al., 2005).

ACKNOWLEDGEMENTS

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REFERENCES

Intelligence in Education (pp. 249-256). Charlottesville, VA: Association for the Advancement of Computing in Education.


APPENDIX A

Note: Refer to Figure 4 for a list of sentence openers

Table 1
Sets of Sentence Openers for Discussion

<table>
<thead>
<tr>
<th>Set Number</th>
<th>Sentence Openers in Set</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1, 3, 5, 6, 7, 8, 9, 10, 11, 18, 19, 20, 22, 28</td>
</tr>
<tr>
<td>2</td>
<td>14, 15, 16, 17</td>
</tr>
<tr>
<td>3</td>
<td>12, 13, 14, 15, 16, 17, 21</td>
</tr>
<tr>
<td>4</td>
<td>1 - 11, 18, 19, 20, 22, 28</td>
</tr>
<tr>
<td>5</td>
<td>1 - 13, 18 - 22, 28</td>
</tr>
<tr>
<td>6</td>
<td>14, 15, 16, 17, 23, 24, 25</td>
</tr>
<tr>
<td>7</td>
<td>14, 16, 17, 18, 21, 23, 24, 25</td>
</tr>
<tr>
<td>8</td>
<td>1 - 13, 15, 19, 20, 22, 28</td>
</tr>
<tr>
<td>9</td>
<td>1 - 13, 15, 19, 20, 22, 27, 28</td>
</tr>
<tr>
<td>10</td>
<td>1 - 11, 14, 16, 17</td>
</tr>
<tr>
<td>13</td>
<td>14, 16, 17, 18, 21, 23, 24, 25</td>
</tr>
<tr>
<td>14</td>
<td>44, 45, 46</td>
</tr>
<tr>
<td>15</td>
<td>12, 13, 15, 20, 27, 28</td>
</tr>
<tr>
<td>16</td>
<td>43, 44, 45, 46</td>
</tr>
<tr>
<td>17</td>
<td>18, 19, 20, 22</td>
</tr>
<tr>
<td>18</td>
<td>43, 44, 45, 46</td>
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<td>43, 44, 45, 46</td>
</tr>
<tr>
<td>20</td>
<td>43, 44, 45, 46</td>
</tr>
<tr>
<td>21</td>
<td>21, 23, 24, 25, 47 (end discussion)</td>
</tr>
<tr>
<td>22</td>
<td>2, 4, 12, 13, 23, 25</td>
</tr>
<tr>
<td>23</td>
<td>26, 27, 29 - 43</td>
</tr>
<tr>
<td>24</td>
<td>26, 29 – 43</td>
</tr>
</tbody>
</table>

Table 2
Sets of Sentence Openers for Creative Conflict

<table>
<thead>
<tr>
<th>Set Number</th>
<th>Sentence Openers in Set</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 - 11, 13, 15, 18 – 22, 24, 26 - 43</td>
</tr>
<tr>
<td>2</td>
<td>12, 13, 15, 26, 27, 29 - 38, 43</td>
</tr>
<tr>
<td>3</td>
<td>1 – 16, 19, 20, 22, 26 - 42</td>
</tr>
<tr>
<td>4</td>
<td>17, 18, 21, 23 - 25</td>
</tr>
<tr>
<td>5</td>
<td>12, 13, 15, 26, 27, 29, 30, 33, 34, 35, 38</td>
</tr>
<tr>
<td>6</td>
<td>1 – 11, 14, 16, 19, 20, 22, 28, 39 - 42</td>
</tr>
<tr>
<td>7</td>
<td>14, 16, 17, 25</td>
</tr>
<tr>
<td>8</td>
<td>26, 27, 29, 31 - 42</td>
</tr>
<tr>
<td>9</td>
<td>18 – 22, 28, 43</td>
</tr>
<tr>
<td>10</td>
<td>1 - 7, 9 – 17, 23, 24, 25</td>
</tr>
<tr>
<td>11</td>
<td>44, 45</td>
</tr>
</tbody>
</table>
Experiment 1
EXPERIMENTAL TASK

As a team, please discuss the following collaborative assignment. Please use either IE or Netscape to log into: http://chester.cs.widener.edu/icss/

Record your thoughts using the webpage as you progress towards a mutually agreed upon solution.

The problem:

Design a database that contains data concerning student records. The database should have tables containing student grades and cumulative averages, as well as personal data such as address, phone number, social security number, and any other data you think should be maintained for each student. Be sure your tables use the social security number as an index. Then create the php pages to access the database tables.

Please think about the solution before beginning to solve it.

Thank you for your assistance.

Experiment 2
EXPERIMENTAL TASK

As a team, please discuss the following collaborative assignment. Please use either IE or Netscape to log into: http://chester.cs.widener.edu/icss/

Record your thoughts using the webpage as you progress towards a mutually agreed upon solution.

The problem:

Consider an arithmetic problem represented in letters, as in:

\[
\begin{array}{c}
\text{SEND} \\
+ \text{MORE} \\
\hline \\
\text{MONEY}
\end{array}
\]

Your task is to assign a decimal digit to each of the letters in such a way that the answer to the problem is correct. If the same letter occurs more than once, it must be assigned the same digit each time. No two different letters may be assigned the same digit.

Please think about the solution before beginning to solve it.

Thank you for your assistance.
APPENDIX C

PRELIMINARY QUESTIONNAIRE

1. Your user name ____________________       Date _________________

2. You are (please circle one): Male       Female

3. Your age at your last birthday? ________________________

4. What is your major? (please circle one)
   - Mathematics
   - Computer Science
   - CIS
   - Engineering
   - Education
   - Liberal Arts
   - Undecided
   - Other:_____________________________

5. Presently, you are a (please circle one):
   - Freshman
   - Sophomore
   - Junior
   - Senior

6. How many computer courses did you have in high school? (please circle one)
   - 0
   - 1-2 courses
   - 3-4 courses
   - 5 or more

7. How many computer courses did you have in college before this one? (please circle one)
   - 0
   - 1-2 courses
   - 3-4 courses
   - 5 or more

8. Have you ever collaborated with other students while solving a problem for a class?
   (please circle one): Yes       No
   If yes, was it successful (did you complete the assignment as a group)?
   (please circle one): Yes       No

9. Have you ever worked with other students while using a computer to solve a problem?
   (please circle one): Yes       No

10. Do you think you would find it beneficial to use a computer to support working in a group?
    (please circle one): Yes       No

11. Do you think you would find it beneficial to work in a group with students who are not known to you?
    (please circle one): Yes       No

12. When you are in the computer lab, how much would you rather compete with a classmate than cooperate
    with him/her?   (please circle one) 1 2 3 4 5 6 7
    Comment:_____________________________________________________

13. When you are in the computer lab, do you feel you benefit from working with other students?
    1 2 3 4 5 6 7
    Comment:_____________________________________________________

14. When you are in the computer lab, do you feel that you don’t understand as much as the other students?
    1 2 3 4 5 6 7
    Comment:_____________________________________________________

15. When you are in the computer lab, how much would you rather work on a programming assignment
    individually rather than in a group?
    1 2 3 4 5 6 7
    Comment:_____________________________________________________

16. Do you feel you would benefit from working in a group while writing a program rather than working
    individually?
    1 2 3 4 5 6 7
    Comment:_____________________________________________________
POST QUESTIONNAIRE

Name: ___________________________ Date: ______________

For each of the following questions, please reply using a five-point scale where:
very poor  poor  fair  good  excellent
1  2  3  4  5

Please circle your response. You may add a supplementary comment or explanation if desired.

1. How would you rate the user-friendliness of the system?
   1  2  3  4  5
   Comment: ______________________________________

2. How would you rate the ease of learning to use the system?
   1  2  3  4  5
   Comment: ______________________________________

3. How would you rate the accuracy of the system? (Accuracy refers to the correctness of the responses displayed by the system)
   1  2  3  4  5
   Comment: ______________________________________

4. How would you rate the usefulness of the “sentence openers”?
   1  2  3  4  5
   Comment: ______________________________________

5. How would you rate the timeliness of the responses made by the system? Timeliness refers to how quickly it responded.
   1  2  3  4  5
   Comment: ______________________________________

6. How would you rate the quality of the responses made by the system? Quality refers to clarity and appropriateness.
   1  2  3  4  5
   Comment: ______________________________________

7. How would you rate the usefulness of the system for accomplishing your individual work?
   1  2  3  4  5
   Comment: ______________________________________

8. How would you rate the usefulness of the system for accomplishing your group work?
   1  2  3  4  5
   Comment: ______________________________________

9. How would you rate the usefulness of the system for discussions with other students?
   1  2  3  4  5
   Comment: ______________________________________

10. How would you rate the ease of using a web browser interface for discussions with other students?
   1  2  3  4  5
   Comment: ______________________________________

11. How would you rate your overall satisfaction with the system?
    1  2  3  4  5
    Comment: ______________________________________

12. How would you rate the success of the system? (Success refers to whether you feel you learned more by using this system than you would have without it.)
    1  2  3  4  5
    Comment: ______________________________________
For the following questions, please circle the answer:

13. The fact that you did not see all members of your group as you worked was not a major hindrance to group performance.
   
   Yes  No

14. You felt the system was helpful when working in a group.
   
   Yes  No

15. You felt more comfortable contributing to the group work when using the system rather than when working face-to-face with other students in a group.
   
   Yes  No

16. You felt like one student dominated the discussion more than others in the group.
   
   Yes  No

17. You felt the system enabled the group to work even though you could not speak to all members directly.
   
   Yes  No

18. You felt intimidated when using the system while working in a group.
   
   Yes  No

19. You felt that the group worked better while using the system.
   
   Yes  No

20. You felt that the group was more productive than you previously thought it would be.
   
   Yes  No

21. You felt that the use of the system contributed to a productive group project.
   
   Yes  No

22. You enjoyed using a web browser as a means to communicate with other students in a group.
   
   Yes  No

23. You would want to use the system again when working on a group assignment.
   
   Yes  No

24. The system sometimes interfered with group work.
   
   Yes  No

25. The system helped your group to exchange ideas.
   
   Yes  No

26. Your group would have finished the project more quickly if all members had been in the same room.
   
   Yes  No  We were in the same room

27. Having the system helped me and others in my group to think of new or better solutions.
   
   Yes  No

28. Did your group complete the assignment?
   
   Yes  No

Please complete if desired:

Are there any additional sentence openers that you would like to see added to the list?

Do you have any suggestions for improving the system?

List one thing that you did not like about the system:
APPENDIX D

Sample Excerpts From Log Files

The following sample excerpts demonstrate the dynamic categorization of the group during a discussion. As sentences are categorized, the student model is incremented, the discussion finite state machine is modified, and the group model is modified to reflect the modifications to the relevant student models. The tallies in the student models are not shown, but rather the group state that results from changes in the student models is shown after each sentence. (The “group state” categories referred to in the following dialogues are discussed in the Group Model section.)

Sample 1 (from Experiment 1, with two students participating):

ted: How would you get into the msql server?
..keyword: Ignore
..category: null: null
..skill: null
..sub-skill: null
..Current State: 4
..group state: MHM
..group prev-state: MHM
(Note: no keyword was recognized, and the state did not change)

matt: Could we try to just start up the server first without a password?
..keyword: Ignore
..category: null: null
..skill: null
..sub-skill: null
..Current State: 4
..group state: MHM
..group prev-state: MHM
(Note: no keyword was recognized, and the state did not change)

ted: I think that’s good
..keyword: Ignore
..category: Task: Trust
..skill: Trust
..sub-skill: Task
..Current State: 7
..group state: HHM
..group prev-state: MHM
(Note: A valid trust skill was used and the group model changed to reflect the use of one more valid communication for the group)

ted: I think that worked. I’ll make the database
..keyword: Ignore
..category: null: null
..skill: null
..sub-skill: null
..Current State: 3
..group state: HHL
...group prev-state: HHM
(Note: One more sentence where no keyword was recognized, and the value of the third component of the group model dropped. This will be addressed as more keywords are added to the rules)

matt:I want to: create the table
.keyword: create
 ..category: Task:null
 ..skill: null
 ..sub-skill: Task
 ..Current State: 3
 ..group state: HHM
 ..group prev-state: HHL
(Note: Working on task once again, so third component went up)

ted:I want to: create the php pages
.keyword: create
 ..category: Task:null
 ..skill: null
 ..sub-skill: Task
 ..Current State: 3
 ..group state: HHM
 ..group prev-state: HHL
(Note: Working on task once again, so third component went up)

**Sample 2 (taken from Experiment 2):**

Louis:Let’s draw a conclusion that: M=1
 ..keyword: Ignore
 ..category: null:null
 ..skill: null
 ..subskill: null
 ..Current State: 6
 sumFOP is 36.0
 localFOP 1 is 0.1388889
 ..GL: Remember everyone needs to contribute to the discussion!
 localFOP 2 is 0.027777778
 localFOP 3 is 0.055555556
 ..group state: MHH
 ..group prev-state: HHH
(Note: The group state was previously HHH, but the Frequency Of Participation for student 2 has dropped below 0.03 and the first group-state value dropped to “M” to reflect this change)

Bob:Yes: but it could be 9
 ..keyword: but
 ..category: BAD_MATCH
 ..skill: null
 ..subskill: BAD_MATCH
 ..GL: You are trying to express several ideas in one sentence. Please re-enter your statements, one idea at a time.
Current State: 6
sumFOP is 45.0
localFOP 1 is 0.11111111
localFOP 2 is 0.022222223
localFOP 3 is 0.06666667
..group state: MMH
..group prev-state: MHH
(Note: The second value in the group model changed to reflect the use of a statement that expresses two different ideas, “Yes” and the segment after “but”. There was no statement from the Group Leader concerning the Frequency of Participation (i.e. the GL did not respond with ‘Remember everyone needs to contribute to the discussion!’) because it was responding to the ‘BAD_MATCH’)

Kathryn:I_think:that S should be 9
..keyword: should
..category: Task:Leadership
..skill: Leadership
..subskill: Task
..Current State: 10
sumFOP is 55.0
localFOP 1 is 0.09090909
localFOP 2 is 0.036363635
localFOP 3 is 0.054545455
..group state: MHH
..group prev-state: MMH
(Note: A valid leadership statement was used and the second value increased to reflect the use of this additional leadership skill)

Louis:I_think_that’s_good:null
..keyword: Ignore
..category: Task2:Trust
..skill: Trust
..subskill: Task2
..Current State: 12
sumFOP is 66.0
localFOP 1 is 0.09090909
localFOP 2 is 0.030303031
localFOP 3 is 0.045454547
..group state: MHH
..group prev-state: MHH
(Note: A valid Trust statement was used but the change in the tallies was not enough to cause a change in any of the three values in the Group Model)