Computer-Supported Structured Cooperative Learning

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Abstract: In this paper we describe computer-supported structured cooperative learning, applied to the laboratories of an introductory CS1 course. We extended I-MINDS, a multiagent system that supports student-teacher and student-student real-time interactions, to support a cooperative learning paradigm called Jigsaw. Jigsaw considers of several phases of activities, including dividing students into different groups for focused exploration, reporting and reshaping, and integration and evaluation. I-MINDS supports the formation of teams and monitors the interaction. We have deployed I-MINDS in the hands-on programming laboratories in CS1, comparing student performance in the lab using only Jigsaw (where students carried out the Jigsaw process with face-to-face interactions) and in the lab using I-MINDS supported Jigsaw (where students could interact only through I-MINDS). We report the results of our study on the design of I-MINDS to support Jigsaw and the impact of I-MINDS in student performance.

Introduction

Most computer-supported collaborative learning (CSCL) systems (e.g., [2-4], [9], [11]) have in general three key weaknesses. First, the collaboration among students are not monitored, measured and analyzed automatically. Vital information on an individual student's collaborative performance and behavior is lost. Further, even when the students' collaborative activities are tracked, real-time analyses are not available automatically to support students or teachers. Second, the collaboration is free-formed and thus not structured. Often times, teachers design various cooperative learning activities using different models to structure how students should collaborate and to target different collaborative strategies to measure. Third, the collaboration among students is not *actively* supported: the CSCL system does not alert the instructor about a student of his or her lack of participation, does not encourage a student to increase his or her participation, and so on.

In our research, our long-term goal is to support *structured* cooperative learning using an intelligent multiagent system where students and instructors may or may not have face-to-face interactions. *Cooperative learning* is basically an instructional strategy where students form small groups or teams and work together to maximize their own and each other's learning [6]. The system will track vital data on student activities to help the instructor monitor and evaluate student progress and performance more accurately and more conveniently. In *structured cooperative learning*, students are guided within a set of prescribed activities so that each activity has a set goal and measurable outcomes. An *agent* is a software module that observes and receives input stimuli from its environment, makes autonomous decisions based on these stimuli, and actuates actions to carry out these decisions, which, in turn, changes the environment and a *multiagent system* is one in which agents work competitively or cooperatively to accomplish task [12]. The advancement of multiagent systems presents a major opportunity to develop an infrastructure in which agents communicate, exchange experiences, and cooperate to better serve the instructors and students.

In the following, we first describe our I-MINDS prototype, which is a CSCL system powered by multiagent intelligence [7]. Then we discuss a structured cooperative learning paradigm called Jigsaw [5]. Subsequently, we present the extension to I-MINDS to support Jigsaw and our study setup. In Section 4, we discuss and analyze the results of our initial deployment of I-MINDS-supported Jigsaw in our introductory CS1 course, specifically in our hands-on programming labs. Finally, we conclude.

1. I-MINDS

I-MINDS (Intelligent Multiagent Infrastructure for Distributed Systems in Education) employs a system of intelligent software agents, representing individual students and the instructor (or teaching resource in the case of an asynchronous course or lesson). The rationale behind using multiagent intelligence is the agent's persistence in tracking and monitoring its environment (student and instructor activities), autonomy in decision making, and responsiveness in providing services to both students and instructors. These are properties that are useful for distance learning and large classrooms.

Briefly, in I-MINDS, each student has a personal agent (a student agent), and each instructor as a personal agent (a teacher agent). All these agents interact with their respective users as well as among themselves. These agents exchange information, coordinate their actions, and track inter-agent activities behind the scene. Currently, a teacher agent, for example, automatically ranks student questions and sorts them for the instructor. A student agent automatically monitors a student's peer group and continuously refine the peer group (by removing and adding new peers) based on the student profiles that the student agent obtain from other agents. Details of the prototype are available from [7-8].

At the current stage, our I-MINDS technology is matured. It has multimedia capability—real-time audio and video streaming such that each student/instructor is able to transmit audio and video through the I-MINDS server. The I-MINDS agents are equipped with (1) tracking capabilities—recording the messages communicated between student agents (or students), the length of each message, the time stamp of each message, each question asked by a student to an instructor or another student, and so on, (2) machine learning capabilities—adjusting weights based on student and instructor actions that feed back to the decision making modules (e.g., how to rate a question, when to make an alert, and so on), and (3) collaborative environments such as chatrooms, token-based digital whiteboards and automated digital archival of notes and lectures. In addition, I-MINDS can be easily downloaded and installed via the Web. When a lecture starts, the teacher opens a session. Students logging in through the Web then join the session accordingly.

2. Jigsaw

2.1 Jigsaw Cooperative Learning Model

The Jigsaw cooperative learning model was first introduced by [1]. This procedure works as follows. First, assign the students into groups. Second, the instructor divides a problem into different parts (or sections). Third, the instructor assigns a part/section for every student such that members of the same group will have different sections to solve. The students who are responsible for the same section then work together to come up with solutions to the section to which they have been assigned and develop a strategy for teaching the solutions to their respective group members. Clarke [5] further refined the Jigsaw structure into stages. These stages are (1) ***Introduction*** of the topic to the class as a whole, (2) ***Focused Exploration***: The focus groups explore issues pertinent to the section that they have been assigned, (3) ***Reporting and Reshaping***: The students return to their original groups and instruct their teammates based on their findings from the focus groups, and (4) ***Integration and Evaluation***: The team connects the various pieces generated by the individual members, address new problems posed by the instructor, or evaluates the group product.

2.2 I-MINDS Supported Jigsaw Cooperative Learning Model

Following the four stages of the Jigsaw structure [5], we have added to the current I-MINDS prototype capabilities that specifically support the last three stages: *Focused Exploration*, *Reporting and Reshaping*, and *Integration and Evaluation*. The current I-MINDS prototype fully supports the Introduction stage with multimedia capabilities. At present I-MINDS assigns an intelligent agent to every student who is in the classroom and assigns a teacher agent to the instructor. These agents help the instructor monitor the student activities and performance. During the introduction phase the teacher agent monitors the performances of all the students in the classroom by classifying and ranking their questions. After the introduction phase the instructor declares the next task and initiates the group formation process. When signaled by the teacher agent, the student agents prompt their assigned students to fill out the *Self Efficacy Questionnaire*. The *Self Efficacy Questionnaire* is a survey that measures how competent the student thinks he or she is to do the assigned task. After the students have posted their *Self Efficacy Questionnaire* the teacher agent chooses the *n* best students from the classroom. These *n* students become the first members of the *n* buddy groups. Here *n* is determined by the number of subtasks the assigned task contains. Then the teacher agent initiates an auction where the remaining student agents bid to join their favorite group. Once the main groups are formed, the teacher agent chooses one student from each group randomly and forms the focus groups. The number of focus groups is equal to the number of subtasks the assigned task consists of. For details on the questionnaires, please refer to [10].

Focused Exploration To support this stage, we have developed focus group agents (FGAs) that, given a particular subtask assigned by the instructor, monitors and support the focus groups. During the focused exploration stage, the goal of the cooperative learning is to encourage the students to explore a particular topic in a focused manner. Thus, active interactions among the students, an increasing focus in their discussions, and a tangible conclusion are expected of such as an activity. Each FGA have the following capabilities to support its focus group: (1) tracking the messages exchanged between the focus groups (2) allowing the focus group to ask questions to the instructor, and (3) monitoring the activities of the exploration and reporting to the instructor of its observation of the progress of the exploration. As part of our continuous enhancement of I-MINDS, we plan to have FGAs that model each student's interaction with his or her focus groups to identify, for example, over-dominating members, sporadic discussions, discussions that are not fruitful, and to prompt discussions by automatically injecting questions or hints.

Reporting and Reshaping After exploration, the students return to their original groups and instruct their teammates based on their findings from the focus groups. Here, we have built buddy group agents (BGAs) to support the reporting and reshaping process. During this stage, the reporting involves sequences of questions and answers (Q&A), with the questions from the teammates and the answers provided by the topic/section expert, which leads to refinement of the topics/sections. Each "buddy" in the group has a chance to be the expert on a particular topic/section and report to his/her teammates. Thus, each BGA have very similar capabilities as those focus group agents. Further, since for each assignment or task, there are multiple sections/topics (and the same number of members per group), there are multiple reporting and reshaping sessions. Each BGA compares the activities of each student as an expert and as a teammate in the buddy group and monitor the student's interaction with his/her buddy group members. At the end of the reporting and reshaping, each team or buddy group prepares a written document of solutions to the assigned task.

Integration and Evaluation At this stage, the team or the buddy group connects the various pieces generated by the individual members. Once the teams have completed the solution to the problem, the student agent prompts the students to fill out a *Team-based Efficacy Questionnaire* to evaluate the performance of their team and a *Peer Rating Questionnaire* to evaluate the performance of their buddy group members. This information is stored in the database and is used by the student agent in future group formation processes.

After the prepared solutions are submitted, the instructor evaluates the integrated results. In future we will expand the teacher agent (TA) in the I-MINDS prototype with the following capabilities: (1) collecting and comparing the solutions to the results of the focus groups—for example, solutions that are too similar to the results of the focus groups indicate that the team has not performed a good job in reshaping the solution, (2) allowing the instructor to grade and score digitally the solutions, (3) allowing the instructor to administer online quizzes and scoring the quizzes, and (4) providing both a student-centric database and a team-centric database how each unit (student or team) performs during the last three stages of the Jigsaw process. Note that for now, we have simplified the role of the agents at this stage and rely on the instructor to be the ultimate evaluator of each group and student. The agents' role here is to provide data and information for the instructor.

3. Implementation

We have extended the original I-MINDS prototype to support structured cooperative learning, specifically Jigsaw. At this stage of our development, I-MINDS+Jigsaw has the following features. The teacher agent has features for specifying a task and its sub-tasks, announcing the task to all student agents, forming buddy main groups and focus groups using a multiagent bidding policy, initiating and ending different phases of Jigsaw, and reporting on the activities of each phase. The student agent has features for responding to the three questionnaires outlined in Section 2 (for details of these questionnaires, please refer to (Soh 2004)), and interacting with different groups of peers. There are also rudimentary versions of the proposed buddy group agents (BGAs) and focus group agents (FGAs). Currently, our focus group agents are able to track the number of messages sent among students in a focus group and score each student based on their performance in a group. All questionnaires, activities, and messages are logged and stored in a mySQL database. We have also implemented a Web-based query interface to conveniently access the database for real-time monitoring and off-line analysis. Ultimately, we aim to incorporate this interface directly into the teacher agent interface as one single package.

We have installed I-MINDS on a server, where an I-MINDS manager (that takes care of student and teacher login and classroom initialization) and the teacher agent reside. Students login on their computers and download and install the student agent on their respective sites. They invoke the student agent executable and log in by supplying the IP address of the server and their username and password. Once everybody is logged in, then the I-MINDS-supported cooperative learning session can begin.

4. Results

Our initial study was designed to (1) compare I-MINDS-supported Jigsaw with simply Jigsaw in terms of student performance, and (2) evaluate how I-MINDS+Jigsaw supports structured cooperative learning. The course chosen for our study was CSCE 155 Introduction to Computer Science, which is the required CS1 core course for computer science students. This course has 3 hours of lectures and 2 hours of lab each week. We deployed our study in the lab. For our CSCE155 course, there were three lab sections, each with about 15 students.

4.1 Experiment Setup

In our study, we utilized two sections. Section one is the "control" section where Jigsaw was used and students were allowed to move around in the lab to have face-to-face discussions during the Jigsaw phases. Section two is the "treatment" section where I-MINDS+Jigsaw was used and students could only interact through I-MINDS. Students were monitored by the lab instructor, as well as two of the co-authors of this paper, to forbid them from interacting directly (face-to-face) during the lab. For each lab, the students were given a lab handout with a list of activities—thus, a lab is a task and its activities are the subtasks. For each activity, the students were required to answer some questions. At the end of the lab, each student was required to take a 10-minute post-test individually. This 10-minute post-test score is our measure of student performance in terms of understanding the topic of the lab.

We ran the above study for three lab sessions: (1) debugging and testing, (2) Unified Modeling Language (UML), and (3) recursion. Questionnaire results and post-test scores of each lab were used to assign the buddy main groups and focus groups in the subsequent lab. In the "Control" section, we did this through manual computation and assignment. In the "Treatment" section, the instructor agent of I-MINDS+Jigsaw automatically carried out this task. Students were assigned to groups such that each group has a balanced mixture of high- and low-performing students.

4.2 Analysis

Table 1 shows the post-test scores of the three sessions for the "Control" (i.e., Jigsaw without I-MINDS) and "Treatment" (i.e., Jigsaw with I-MINDS) sections. The results indicate that students using I-MINDS for the Jigsaw activities were able to obtain comparable and even better post-test scores. Students in the Treatment section performed better than the students in the Control section in the later two sessions. Further, students in the Treatment section also achieved better standard deviation—meaning that these students' post-test scores were more tightly clustered than those of the Control section. This is very encouraging: without face-to-face interactions, students carried out their I-MINDS-supported Jigsaw tasks and performed relatively well in individual post-tests. However, we will need more data and more in-depth analysis to validate the significance of this finding.

Post-Test Scores (max. 10)	**Session 1**		**Session 2**		**Session 3**	
	Average	**Std. Dev.**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**
Jigsaw without I-MINDS	7.06	1.83	5.00	2.41	8.83	2.85
Jigsaw with I-MINDS	6.10	1.79	7.63	1.72	9.00	1.50

Table 1. Student performance for the Control (Jigsaw without I-MINDS) and Treatment (Jigsaw with I-MINDS) sections.

Table 2 compares the Control section and the Treatment section in terms of self-efficacy, peer rating, and team-based efficacy.

- The *self-efficacy* questionnaire was conducted at the beginning of each lab session. It is a self-report of how a student feels about his or her ability about understanding topic and carrying out the activities of the lab. In general, students in the Treatment section had a slightly lower self-efficacy. This is interesting as these were the same students who scored better than the students from the Control section in Sessions 2 and 3.
- The *peer rating* average is the average peer rating scores that each student gave to his or her group members. As evidenced in the scores, students in the Control section rated their peers better than the students in the Treatment section. This is possibly due to the face-to-face interaction. After all, students interacting through I-MINDS could not enjoy the advantages of face-to-face interactions such as facial expressions, the spontaneous free-flowing of ideas, and more immediate feedback in their discussions. Also, with students sitting nearby in a group, it was more engaging. This observation shows that to rival the more intuitive interactions in the face-to-face interactions, I-MINDS would need improvements in its graphical user interface and multimedia features.
- The team-based efficacy was collected after each lab based on a set of questions. It measures how a student views how well its group has performed. Once again, students in the Control section approved of their team-based activities more than the students in the Treatment section.

	Session 1		**Session 2**		**Session 3**	
	Average	**Std. Dev.**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**
Self Efficacy (max. 45)						
Jigsaw without I-MINDS	33.87	4.41	35.00	3.30	34.83	2.28
Jigsaw with I-MINDS	32.36	4.00	33.40	5.35	33.77	3.80
Peer Rating (max. 45)						
Jigsaw without I-MINDS	42.02	2.68	39.06	7.05	39.90	4.80
Jigsaw with I-MINDS	35.60	5.97	33.30	8.65	38.59	6.34
Team-Based Efficacy (max. 35)						
Jigsaw without I-MINDS	29.87	2.51	31.86	3.48	30.08	3.02
Jigsaw with I-MINDS	27.72	5.08	29.20	2.78	28.25	4.02

Table 2. Questionnaire Results: Self-Efficacy is pre-Jigsaw activities; Peer Rating and Team-Based Efficacy are post-Jigsaw activities.

Table 3 presents a sample of the individual students' rating of their peers in the Treatment section, averaged over the three lab sessions. Computing correlations of each evaluation vs. the post-test scores, we observe that only two evaluations are highly correlated with the post-test scores. First, average peer rating that a student gave to his or her peers is negatively correlated to his or her post test score with a correlation of -0.63. We suspect that when a student is critical of his or her peers, the student is more aware of the different levels of abilities and is more confident of him- or herself. This means that the student is also more likely to do well in the post-test. Second, though the number of messages that a student sent to his or her group is not correlated to the student's post-test score (only 0.03), the length of messages sent is (0.51). This provides a valuable insight to how we should measure student contribution to a group in the future: students who do well in the post-tests tend to send long messages.

Table 4 shows a sample of the group members of a student rated the student or the student's group. Once again, the average length of messages sent within the group is highly correlated with the student's post-test score (0.62). This correlation is actually higher than that found in Table 3, hinting that how the group behaves could help improve the student's post-test score. Further, how the group rated the peers only slightly correlates with the post-test score (-0.24). In addition, the correlations of other evaluations vs. the post-test scores are greater than their counterparts in Table 3. This gives positive hint that group activities could help with a student's performance, and our questionnaires and the messages tracked could be used as indicators. This encourages us to extend our analysis and tests in this direction for our future work.

Table 5 shows the average number of messages sent during each Jigsaw Phase. The Reporting and Reshaping (Phase 3) phase yielded the most messages sent while the Integration and Evaluation (Phase 4) phase the least. The drop-off in the number of messages sent during Phase 4 makes sense as students tend to relax after the intensive Phase 2 and Phase 3 discussions.

Student ID	**Average Peer Rating (max. 45)**	**Average Team-Based Rating (max. 35)**	**Average % of Work Done by Team**	**Average % of Work Done by Student**	**Average Number of Messages Sent**	**Average Length of Messages Sent (chars)**	**Student's Average Post-Test Scores**
s6	34.8	28.0	37.5%	62.5%	31.7	94.5	**8.0**
s10	41.4	17.0	5.0%	95.0%	19.7	28.8	**7.0**
s12	38.5	28.5	55.0%	45.0%	9.0	22.2	**7.0**

Table 1. A sample of individual student's perception or evaluation of his or her group and the activities within the group. All numbers are based on a student's viewpoint of his or her group members or a student's actions to his or group members (except for the last column).

Student ID	**Group's Peer Rating of Student (max. 45)**	**Group's Team-Based Rating (max. 35)**	**Group's view of %Work Done by Team**	**Group's view of %Work Done individually**	**Group's Average Total # Messages Sent**	**Group's Average Length of Messages Sent (chars)**	**Student's Average Evaluation**
s6	39.4	27.6	46.1%	53.9%	43.2	65.6	**8.0**
s10	36.7	29.6	31.6%	68.4%	34.0	78.4	**7.0**
s12	37.6	26.3	50.8%	49.2%	40.5	56.8	**7.0**

Table 2. A sample of group members' perception or evaluation of a student's group and the activities within the group. All numbers are based on the average group's viewpoint or the aggregate group's actions (except of the last column).

	Jigsaw Phase 2	**Jigsaw Phase 3**	**Jigsaw Phase 4**
Average Number of Messages	113	160.33	62.33

Table 5: Average number of messages for each Jigsaw phase.

5. Conclusions and Future Work

We have described our extension of I-MINDS, a computer-supported collaborative Learning system, to support structured cooperative learning. Specifically, we have added features to support the Jigsaw procedure. We have deployed the I-MINDS+Jigsaw system three lab sessions of CS1. Initial results are encouraging. We have found out that students, without the benefit of face-to-face interactions, were able to make use of I-MINDS+Jigsaw, and performed as well as students with face-to-face interactions in the post-test of each lab. However, we have also observed that students rated their team activities more highly in face-to-face interactions. Further, we have also found significant correlations between the length of messages sent and a student's performance. There are also indications that when a student is critical of his or her peers, this student's post-test score is likely to be higher. Also, there seems to be hints that group activities do help improve students' post-test scores. We will continue to enhance I-MINDS to fully incorporate the Jigsaw procedure, and improve the intelligence of the group agents. Our future work also includes further analysis, tying student performance to classroom achievement and individual group performance.

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