Agent-Based Cooperative Learning: A Proof-of-Concept Experiment

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ABSTRACT

This paper presents an innovative multiagent system to support cooperative learning among students both in the real classrooms and in distance education. The system, called I-MINDS, consists of a group of intelligent agents. A teacher agent monitors the student activities and helps the teacher manage and better adapt to the class. A student agent, on the other hand, interacts with the teacher agent and other student agents to support cooperative learning activities behind-the-scene for a student. Two I-MINDS innovations are (a) agent-federated "buddy group" formation and (b) automated ranking of questions and responses. We have tested our I-MINDS prototype with experiment and control groups to evaluate the impact of I-MINDS in learning. The results are encouraging.

Categories and Subject Descriptors
Distance Education, Information Systems, Classroom Management

General Terms
Design, Experimentation

Keywords
Multiagent Systems, Cooperative Learning

1 INTRODUCTION

In this paper, we describe an innovative multiagent system that supports cooperative activities among students through the use of intelligent agents. This system, applicable to students both in the classroom and remote, monitors students' and teacher's activities to help the teacher teach better and students learn better.

As pointed out in [8], research strongly supports the user of technology as a catalyst for improving the learning environment. Educational technology has been shown to stimulate more interactive teaching, effective grouping of students, and cooperative learning.

According to Sheppard *et al.* [14], the motivations behind using technologies in learning are related to the beliefs that they

- are inherently good
- are needed to remain competitive as an institution
- make the delivery of education more cost effective
- open up possibilities of reaching new/different student groups
- offer students more control over when and where they interact with "knowledge"
- offer more and new opportunities for student-student and student-faculty interaction
- offer new opportunities for cross-university interaction by both students and faculty
- offer students richer, more diverse learning resources and alternate points-of-view
- offer opportunities for documenting, cataloguing and re-using curriculum materials and student work

Our system, called the Intelligent Multiagent Infrastructure for Distributed Systems in Education (I-MINDS), incorporated technology to support and encourage cooperative learning among students in a real-time classroom, for either distance education or in-class students. The motivations behind our project are three-fold: (a) to address or improve areas in education (e.g., distance education) in line of the reasons (competitiveness, cost-effectiveness, student control, student-student interactions, student-faculty interactions, and management of curriculum materials and student work) outlined by Sheppard [14] above, (b) to investigate and ultimately adopt innovative techniques in Computer Science (such as multiagent intelligence) and Computer Engineering (such as distributed computing) in the advancement of education tools, and (c) to investigate cooperative learning from the viewpoint of instructional technology and action research, by using I-MINDS as an active, flexible testbed.

In the following, we first define what agents are and some related work in educational applications. In Section 3, we describe the design and methodology behind our teacher and student agents, and how two innovations are embedded into these agents to (a) automatically rank students' questions and responses, and (b) automatically form and refine "buddy groups" for the students. A buddy group, in our context, is a close-knit student group where its members exchange messages and help each other understand the lectures. Also, in the section, we will discuss the features that make I-MINDS more than just a lecture-delivery tool. In Section 4, we report on the experiments that we have conducted using our I-MINDS prototype, and show that the preliminary results are encouraging. Finally, we conclude.

2 BACKGROUND

First, let us define some terms within the context of this paper.

An *agent* is a 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 [17].

An *intelligent agent* is a flexible agent that is pro-active, reactive, or social [18] and able to *learn* to improve its own performance [13]. Most software tutors (or Intelligent Tutoring Systems) [4] are based on knowledge-based systems or single agents. For example, SAM [3], intelligent interfaces such as AIP, PIP, and IMP [1], PAT [12], Animated Pedagogical Agents [7], AutoTutor [4, 5], Herman the Bug, and Cosmo the Internet Advisor [9] utilize single agents to observe and adapt to the different behaviors of students. Because these agents work independently of each other, they fail to utilize the potential of *multiagent intelligence* [17]. 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. I-MINDS exploits this opportunity.

Only a few systems make use of multiagent intelligence, and those that do only monitor different agents to conduct team performance analysis, such as PROBES [10] and ISSAC [11]. I-MINDS agents move beyond monitoring to actively and autonomously seek out buddies for their users and learn to refine the buddy group. Finally, one of the abilities needed in software tutors is self-improvement [19]. That is, agents should be able to *learn* to help teachers teach better and to help students learn better—some have argued that only agents that learn are truly intelligent agents [18]. I-MINDS agents learn: the teacher agent learns how to evaluate the students and how to evaluate the responses of the students. The student agents learn how to form more effective buddy groups and how to help their fellow students in active and cooperative learning processes.

3 THE DESIGN OF I-MINDS

The development and implementation of I-MINDS is a unique and innovative approach to computer-aided instruction and learning because of the incorporation of active and intelligent software agents. I-MINDS includes both student agents and a teacher agent. Student agents collaborate to autonomously form student *buddy groups* and provide intelligent services to their respective student users. Teacher agents monitor classroom activities and analyze student behavior to help the teacher respond to questions and to assess student comprehension and interest. These intelligent agents are designed to assess their own performance based on the observed impact of the buddy groups and the agent-initiated interventions, such as question ranking, on student learning

The first I-MINDS innovation is in agent-federated "buddy group" formation. A buddy group *is a team* (or "coalition") that is formed dynamically to support the members, or buddies, within the group to achieve common goals. Student agents, profiling the activities of their respective students/learners, seek out compatible student agents to form buddy groups, allowing a free-flow of questions and answers between members of the same buddy group. A "good buddy" with good responses will be ranked high and preferred for close collaboration. A "poor buddy" who never responds, for example, will be removed from the buddy group. We plan to incorporate a cooperative learning model [6] using proven concepts to extending the expertise and intelligent components of our I-MINDS agents in the future.

The second innovation is the automated ranking of questions and responses for the instructor using agent intelligence. Each question or response from a student will be analyzed and ranked for the instructor according to its appropriateness, quality of information content, etc. Currently, such rankings are based on keyword selection. This selection also teaches the agent to learn to evaluate questions better, making the agent highly adaptive and dynamic. A key component of this innovation is that it encourages interaction and, thus, active learning [2, 15]. As noted in the section on the proof-of-concept study, student questions asked through I-MINDS tended to be higher quality and required more information-rich responses than those asked by a control group in a traditional classroom setting.

The I-MINDS prototyping process was initiated in September 2002 using a National Center for Information Technology in Education (NCITE) Seed Grant, which allowed us to build a "proof-of-concept" software package and conduct preliminary experiments to evaluate the technical correctness and educational feasibility of I-MINDS. The prototype was developed and built in Java. Two types of agents were designed and implemented, along with a host of technologies (Table 1) to support the agents.

Technology
Live audio (2-way)
Live video (1-way)
Superimposition of handwriting (MIMIOS) on lecture screen, superimposition of text on archived lecture pages
Automated archival
Multicast/broadcast
Multicharacter forum and chat room (colors and fonts)
Multicharacter e-whiteboard (colors and fonts, exclusive tokens)
Annotation and asynchronous review of archived lectures
Rich and flexible control of system features

Table 1. Technology implemented for I-MINDS.

In the following, we briefly describe the current I-MINDS prototype, focusing on the two types of agents (teacher agent and student agent) and their underlying methodologies, and the delivery technologies developed.

Please refer to [16] for a detailed technical description of I-MINDS.

3.1 Teacher Agent

Figure 1 shows the structure of the I-MINDS teacher agent.

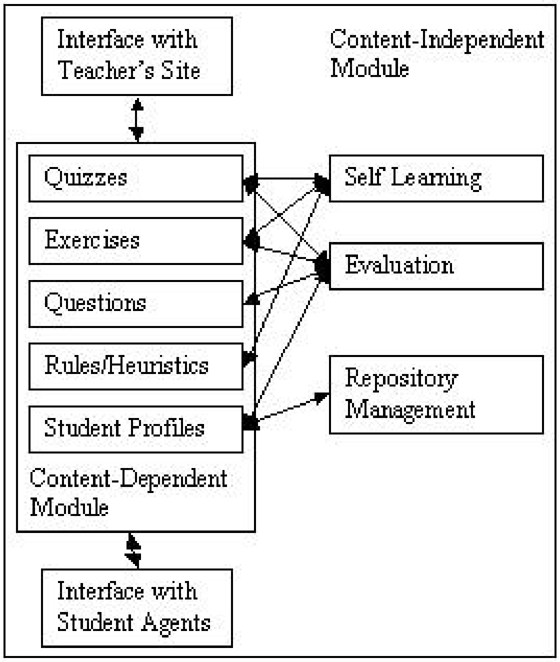

Figure 1. Structure of the I-MINDS teacher agent. Note that the "Teacher's Site" refers to the operating System and multimedia components to which the Teacher agent interfaces.

In the Content-Dependent Module are quizzes/exercises and answers from all the students, questions asked by students, rules used for inference, and dynamic profiles of the students. The profile of a student is a score based on the student's questions and cooperative learning activities. The I-MINDS teacher agent automatically monitors and logs these into its database. The profiles allow the teacher agent to rank questions and help the student agents build buddy groups. The rules used to evaluate the quality of the questions and the buddy groups will be evolved by I-MINDS based on their utility. The Evaluation mechanism evaluates the students based on their responses to the exercises and the quizzes as well as the monitored questions and actions from their student agents. These profiles also factor into the Self-Learning activity. For example, the teacher agent will be able to learn which keywords and heuristics are useful to improve the quality of questions from the students. Finally, a Repository Management mechanism caches sizable teaching materials into large storage devices for efficient transmission.

Currently, we have implemented some of the Content modules such as questions, rules/heuristics, and student profiles of the teacher agent and have implemented both of the Interface modules and part of the Evaluation module. We have also implemented a prototype of the Student Profile module and a definition of a student profile. The response by each student through his/her respective student agent is evaluated, and the cooperative learning activities among students are captured automatically by the teacher agent.

3.2 Student Agent

Figure 2 depicts the structure of the I-MINDS student agent. The student agent displays messages and information streams received from a teacher agent directly to the student. Similarly, the student agent forwards the responses from the student to the teacher agent.

The Tracking mechanism tracks the activities and the progress of the student. For example, if the student does not touch the keyboard or move the mouse for five minutes during a class, the student agent may play a sound to alert the student to concentrate on class. If the student misses one class, the Tracking mechanism may go to the corresponding teacher agent, find the archived materials for that class according to the timestamps or the syllabus the teacher provides, and remind the student about the missed lectures.

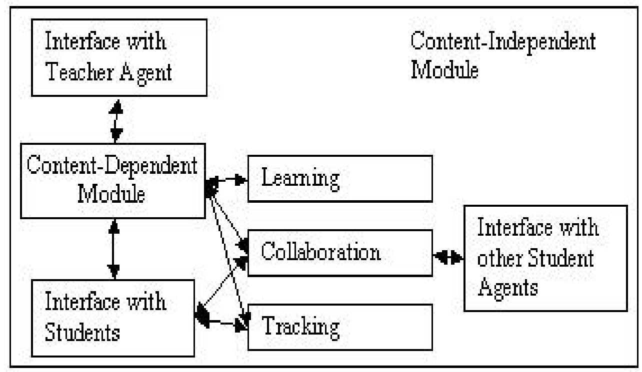

Figure 2. Structure of the I-MINDS student agent.

Each student agent has a Collaboration mechanism that can be activated by the student. When a student asks a question, the student agent sends it to the teacher agent. In addition, the student agent sends the question to the other student agents identified as buddies by the first student's agent. Thus, buddies may answer questions that the teacher does not respond to in class (see Student Scenario in Figure 1). Buddies that have not been responsive will be dropped from the buddy group; buddies that have been helpful will be approached more frequently. The student agent performs these tasks for its user autonomously.

To date, we have implemented the student agent's three interfaces, parts of the Collaboration module, and parts of the Content-Dependent Module and the Learning module. The I-MINDS student agents are able to form buddy groups dynamically based on the information shared among the student agents. Thus, the I-MINDS design employs multiagent intelligence to form and refine cooperative learning teams.

4 EXPERIMENTS AND EVALUATION

To determine the potential impact of I-MINDS on student learning, a pilot study was conducted in May 2003 where the tool was used by subjects in a controlled experiment to assess what impact it had on student learning of Global Information Systems (GIS) content. GIS technology can be used for scientific investigations, resource management, and development planning.

Tables 2 and 3 document the key specifics of the pilot study. On Day 1, subjects in both groups completed a 109-point pretest of the content that was to be taught during the two sessions. At the conclusion of the class on Day 1 for both groups, the subset of 60 items that related to the content of that class was included on the posttest. After the Day 2 instruction, the subset of 49 items that related to the content of that class constituted the posttest. Subjects in the control group learned the identical content during each of the two sessions, as did subjects in the experimental group. The difference was that the control group students were in the same room as the instructor. Their class was taught in a very traditional manner with the professor using PowerPoint slides identical to those used for the experimental group to teach the content.

Specifics of the Pilot Study
All sessions taught by the same instructor
20 undergraduate and graduate students participants
Two groups: Control and Experimental Groups
Each subject received $90 for their participation
This study received IRB Approval.

Table 2. Specifics of the pilot study.

Experiment Group	**Control Group**
Day 1 • I-MINDS Training (30 min.) • Pretest (45 min) • Break (15 min) • Class (60 min) • Distracter Task (5 min) • Posttest (30 min)	**Day 1** • Pretest (45 min) • Break (15 min) • Face-to-Face Class (60 min) • Distracter Task (5 min) • Posttest (30 min)
Day 2 • I-MINDS Training (15 min) • Class (60 min) • Break (15 min) • Distracter Task (5 min) • Posttest (30 min) • Perception Survey (5 min)	**Day 2** • Face-to-Face Class (60 min) • Break (15 min) • Distracter Task (5 min) • Posttest (30 min) • Perception Survey (5 min)

Table 3. I-MINDS pilot study groups and events.

Separate 2 x 2 (group by pretest-posttest) mixed-model analyses of variance were used to determine the effect of using I-MINDS on learning in the experiment (Table 4). Cell means and marginal means for the two groups for the two factors appear below for each day the subjects were tested.

Test 1			
Group	**Pretest**	**Posttest**	**Marg.Means**
I-MINDS	13.1	33.4	23.25
Control	17.4	41.3	29.35
Marg.Means	15.25	37.5	

Test 2			
Group	**Pretest**	**Posttest**	**Marg.Means**
I-MINDS	12.0	22.2	17.1
Control	15.78	20.67	18.2
Marg.Means	13.79	21.47	

Table 4. Test results.

Results for Test 1 revealed a significant main effect for the group factor, $F(1,18) = 5.03$, $p<.05$, with subjects in the control group scoring significantly higher than subjects in the I-MINDS group. This means there was a significant difference found between the two marginal means for this factor. Note that the numbers 1 and 18 refer to the degrees of freedom for the numerator and denominator terms of the analysis. The first number is the number of levels of this factor minus 1, and the second number corresponds to the degrees of freedom for the error term. The main effect for the repeated measures was also significant, $F(1,18) = 131.90$, $p < .01$. The scores on the posttest were much higher than were scores on the pretest. No significant interaction was found, $F(1,18) = .88$, $p> .05$. Results for Test 2 revealed no significant main effect for the group factor, $F(1,17) = .17$, $p>.05$. As was the case for Test 1, the main effect for the repeated measures was significant, $F(1,17) = 17.59$, $p < .05$. The scores on the posttest means collapsed across groups were higher than were scores on the pretest. No significant interaction was found, $F(1,17) = 2.18$, $p> .05$.

Results for the two testing sessions are encouraging. For the initial testing session, it was expected that the control group would either score better than the I-MINDS group or be no different due to the inexperience of both the subjects and the instructor in using the new teaching and learning tool. The training session that preceded the class allowed the subjects to acquire some degree of skill for this first session, but it was hardly sufficient to master the numerous I-MINDS tools.

During the week between Test 1 and Test 2, subjects in the I-MINDS group commented about how they had considered ways to use the software to assist their learning. Although there was a slight difference in the means of the experiment and control groups for Test 2, this difference was not statistically significant (p> .05), and *the amount that the I-MINDS group improved from the pretest to the posttest was nearly twice that of the control group*. This result was very promising as were comments from the subjects in the I-MINDS group related to their comfort level in using the tool.

Comments from the university professor who used I-MINDS in teaching both of the content lessons were also encouraging. He indicated that the teaching tool was very easy to learn and use. He also said that the tool could enhance distance learning, especially by making it possible for building an archive of information that could be accessed "on-demand" by students. The instructor also noted that questions asked of him via I-MINDS tended to be higher quality, reflect a deeper understanding, and demand a richer response than those questions posed during the control sessions.

5 FUTURE WORK

Our future work for I-MINDS is three-pronged.

First, we plan to bring I-MINDS into deployment and services in the near future. For example, we aim to incorporate I-MINDS into our department-wide Reinventing CS Curriculum, which has been on-going for the past year. Initially, we plan to use I-MINDS in laboratories where paired programming assignments are available. In addition, we want to deploy I-MINDS to support distance education where remote students will be able to use I-MINDS to (a) interact with the instructor and students real-time, (b) interact with the lectures and students in the buddy group off-line through digital archives and digital forums (both available in the current version of I-MINDS), and (c) interact with fellow students in research and project groups such that an instructor can evaluate the roles of the students in a group and assign individual grades more fairly.

Second, we will continue to improve I-MINDS along two fronts. First, we will address the operational issues in scalability, consistency and security. We plan to extend I-MINDS to large and diverse audience that may have different bandwidth, information need, and computing constraints. Second, we want to enhance the intelligence of the I-MINDS agents in machine learning—how can each agent learn to adapt to different instructors, students, lectures, and classrooms? To this end, we will also incorporate instructional paradigms in cooperative learning, especially team building. The student agents will adhere to proven techniques and guidelines in team building and also evaluate the quality and progress of a team.

Finally, we see in the future more extensive and comprehensive tests using I-MINDS, primarily in student learning, and secondary in teacher learning. We want to collect data on how students learn with technology, and how students behave with "buddy groups." We want to observe how teachers learn from using I-MINDS as well.

6 CONCLUSIONS

We have presented an innovative multiagent system to support cooperative learning among students both in the real classrooms and in distance education. The system, called I-MINDS, consists of a group of intelligent agents. A teacher agent monitors the student activities and helps the teacher manage and better adapt to the class. A student agent, on the other hand, interacts with the teacher agent and other student agents to support cooperative learning activities behind-the-scene for a student. We have described two I-MINDS innovations in (a) agent-federated "buddy group" formation and (b) automated ranking of questions and responses. We have reported on the proof-of-concept test of the I-MINDS prototype. The results, as reported, are encouraging. Our future work includes deploying I-MINDS to classrooms, improving I-MINDS technically, and conducting further experiments to learn about technology-supported learning in CS curriculum.

7 ACKNOWLEDGEMENT

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REFERENCES

[1] André, E. and T. Rist (2001). Controlling the Behavior of Animated Presentation Agents in the Interface: Scripting versus Instructing, *AI Magazine*, 22(4):53-66.

[2] Bonwell, C. C. and J. A. Eison (1991). Active Learning: Creating Excitement in the Classroom, *ERIC Clearinghouse on Higher Education*, Document No. ED 340 272.

[3] Cassell, J. (2001). Embodied Conversational Agents: Representation and Intelligence in User Interfaces, *AI Magazine*, 22(4):67-83.

[4] Graesser, A. C., K. VanLehn, C. P. Rosé, P. W. Jordan, and D. Harter (2001). Intelligent Tutoring Systems with Conversational Dialogue, *AI Magazine*, 22(4):39-51.

[5] Graesser, A. C., K. Wiemer-Hastings, P. Wiemer-Hastings, R. Kreuz, and the Tutoring Research Group (1999). AutoTutor: A Simulation of a Human Tutor, *Journal of Cognitive Systems Research*, 1(1):35-51.

[6] Johnson, D. W., R. T. Johnson, and K. A. Smith (1991). Cooperative Learning: Increasing College Faculty Instructional Productivity, *ASHE-ERIC Higher Education Report No. 4*, George Washington University.

[7] Johnson, W. L., J. W. Rickel, and J. C. Lester (2000). Animated Pedagogical Agents: Face-to-Face Interaction in Interactive Learning Environments, *International Journal of Artificial Intelligence in Education*, **11**:47-78.

[8] Kadiyala, M. and b. L. Crynes (1998). Where's the Proof? A Review of Literature on Effectiveness of Information Technology in Education, in *Proceedings of 1998 FIE Conference*, 33-37.

[9] Lester, J. C., C. B. Callaway, J. P. Grégoire, G. D. Stelling, S. G. Towns, and L. S. Zettlemoyer (2002). Animated Pedagogical Agents in Knowledge-Based Learning Environments, in Forbus, K. D. and P. J. Feltovich (2002). (Eds.) *Smart Machines in Education*, Menlo Park, CA: AAAI Press, pp. 269-298.

[10] Marsella, S. and W. L. Johnson (1998). An Intelligent Assistant for Team Training in Dynamic Multi-Agent Virtual Worlds, in *Proceedings of Intelligent Tutoring Systems, 4th International Conference*, 464-473.

[11] Raines, T., M. Tambe, and S. Marsella (2000). Automated Assistants to Aid Humans in Understanding Team Behaviors, in *Proceedings of the Fourth International Conference on Autonomous Agents*, 419-426.

[12] Rickel, J. and W. L. Johnson (1999). Animated Agents for Procedural Training in Virtual Reality: Perception, Cognition, and Motor Control, *Applied Artificial Intelligence*, **13**(4):343-382.

[13] Sen, S. and G. Weiss (1999). Learning in Multiagent Systems, in Weiss, G. (ed.), *Multiagent Systems: A Modern Approach to Distributed Artificial Intelligence*, MIT Press, pp. 259-298.

[14] Sheppard, S. D., D. Reamon, L. Friedlander, C. Kerns, L. Leifer, M. Marincovich, and G. Toye (1998). Assessment of Technology-Assisted Learning in Higher Education: It Requires New Thinking by Universities and Colleges, *Proc. 1998 FIE Conference*, 141-145.

[15] Silberman, M. (1996). *Active Learning: 101 Strategies to Teach Any Subject*, Allyn & Bacon.

[16] Liu, X., X. Zhang, L.-K. Soh, J. Al-Jaroodi, and H. Jiang (2003). A Distributed, Multiagent Infrastructure for Real-Time, Virtual Classrooms, accepted to *International Conference on Computers in Education (ICCE2003)*, Hong Kong, China.

[17] Weiss, G. (ed.) (1999). *Multiagent Systems: A Modern Approach to Distributed Artificial Intelligence*, MIT Press.

[18] Wooldridge, M. and N. R. Jennings (1995). Intelligent Agents: Theory and Practice, *The Knowledge Engineering Review*, 10(2):115-152.

[19] Woolf, B. P., J. Beck, C.Eliot, and M. Stern (2002). Growth and Maturity of Intelligent Tutoring Systems: A Status Report, in Forbus, K. D. and P. J. Feltovich (2002). (Eds.) *Smart Machines in Education*, Menlo Park, CA: AAAI Press, pp. 99-144.