A Wiki with Multiagent Tracking, Modeling, and Coalition Formation

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Abstract

Wikis are being increasingly used as a tool for conducting collaborative writing assignments in today's classrooms. However, Wikis in general (1) do not provide group formation methods to more specifically facilitate collaborative learning of the students and (2) suffer from typical problems of collaborative learning like detection of free-riding (earning credit without contribution). To improve the state of the art of the use of Wikis as a collaborative writing tool, we have designed and implemented ClassroomWiki—a Web-based collaborative Wiki that utilizes a set of learner pedagogy theories to provide multiagent-based tracking, modeling, and group formation functionalities. For the students, ClassroomWiki provides a Web interface for writing and revising their group's Wiki and a topic-based forum for discussing their ideas during collaboration. When the students collaborate, ClassroomWiki's agents track all student activities to learn a model of the students and use a Bayesian Network to learn a probabilistic mapping that describes the ability of a group of students with a specific set of models to work together. For the teacher, ClassroomWiki provides a framework that uses the learned student models and the mapping to form student groups to improve the collaborative learning of students. ClassroomWiki was deployed in three university-level courses and the results suggest that ClassroomWiki can (1) form better student groups that improve student learning and collaboration and (2) alleviate free-riding and allow the instructor to provide scaffolding by its multiagent-based tracking and modeling.

Introduction

Wikis provide a useful platform for conducting collaborative writing in today's classrooms (Cole 2009; Forte and Bruckman 2007; Trentin 2009; Steve Wheeler, Yeomans, and Dawn Wheeler 2008). In typical collaborative writing assignments in a Wiki, students collaborate and cooperate to write an essay on the instructor's chosen topic and learn the topic from the collaboration and interaction (Cress and Kimmerle 2008). Due to the collaborative nature of the assignment, the learning outcome in Wikis depend on how well the group members collaborate among themselves which is determined by collaborative learning-related aspects like (Roberts and McInnerney 2007) (1) *group formation* and (2) *individual assessment of student contributions and performances*.

The composition of student groups impacts their ability to collaborate because not all groups have the same ability to collaborate. For example, researchers (Cress and Kimmerle 2008; Inaba et al. 2000; Issroff and Jones 2005) found that various student attributes such as their knowledge and collaboration skills impact their collaborative learning outcomes. So, a Wiki environment that models the students and their collaborations to learn the composition of members that improves their collaboration is useful. Another issue in collaborative writing is accurate assessment of individual students' contributions toward the group. Lack of accurate contribution assessment gives rise to lack of accountability (Roberts and McInnerney 2007), decreased collaboration (Ebner, Kickmeier-Rust, and Holzinger 2008), and may negatively impact the collaborative learning outcome. In other words, a Wiki tool that allows the teacher to track the students' activities to better assess their individual contributions towards their groups would *motivate* the students to collaborate better. Such improved tracking would also allow the teacher to provide specific and precise interventions in a timely manner.

In this paper, we describe ClassroomWiki, a Web-based computer-supported collaborative learning tool that we have built combining (1) a set of theories on student pedagogy that explain the collaborative learning process in Wikis with (2) the tracking, modeling, and group formation capabilities of a Multiagent Human Coalition Formation (MHCF) framework (based on (Soh and Khandaker 2007)) to form student groups. Briefly, in MHCF, a set of intelligent agents (1) track the students' activities in the environment to learn a model of the students and (2) use a Bayesian Network to learn the probabilistic mapping of a group of students' models onto their performances in the current and future tasks. Using their learned models and mapping, the agents then negotiate to form student groups

that allow the members to solve the current task well *and* learn how to solve the future tasks better.

Note that we have previously published the framework and architecture of ClassroomWiki including the summary of the results of our 3-week-long preliminary deployment in (Khandaker and Soh 2009). Furthermore, we have published the preliminary results of our three-month-long deployment of ClassroomWiki in (Khandaker and Soh 2010). In this paper, we report on (1) previously unpublished results, specifically, the users' and teachers' experiences, (2) the *newly obtained* results on the impact of the use of our agent-based technology in tracking, modeling, and group formation in ClassroomWiki, and (3) our ongoing deployments to further validate the usefulness of ClassroomWiki.

Problem and Solution Approach

Collaborative Knowledge Building in Wikis

Cress and Kimmerle (2008) model the collaborative knowledge building with Wikis as a two-component system composed of (1) a social system, i.e., the Wiki and (2) a cognitive system, i.e., the students' cognitive processes. Cress and Kimmerle discuss that through the structural coupling based on *language*, the social system is able to effect changes into the participating learners' cognitive system through externalization and internalization. While working in the Wiki environment, learners contribute to topics or create artifacts which they have some knowledge on—i.e., the externalization process. On the other hand, the internalization process refers to the integration of the knowledge contained in the Wiki artifacts prepared by other learners. Thus the externalization process of one learner contributes to the internalization process of another and this collaboration increases the knowledge of the learner who internalizes that knowledge. This internalization also interacts with the knowledge a learner already has to produce *new emergent* knowledge.

Group Formation Problem

With the model described in the previous approach, students learn from each other through externalization and internalization process. This implies that what a student *knows* (i.e., his or her knowledge) and *how well* they collaborate with their group members impact that group's collaborative learning outcomes. So, a framework that forms student groups should *utilize the impact of the knowledge and collaboration skills of a group on its collaborative learning outcomes*.

Note that in a Wiki environment, the impact of the knowledge and collaboration skills of the students would vary according to the environment—such as the collaborative writing assignment and the communication modes available—and the learner's characteristics. Furthermore, the expertise of the learners in a collaborative learning setting evolves as they progress through their syllabus and coursework. Thus, the formed groups need to reflect those changes in learner characteristics.

Definition – *The group formation problem in our Wiki environment refers to dividing the set of students into a disjoint set of groups according to their changing characteristics so that the group structure improves their collaborative learning outcomes.*

Tracking and Modeling Problem

Accurate tracking and modeling of student contributions towards their groups is not available in most collaborative learning and writing environments. This lack of tracking and modeling leads to free-riding and as a result: (1) free-riding students receive credits without doing work (Roberts and McInnerney 2007), (2) hard-working students are discouraged from collaborating (Roberts and McInnerney 2007), and (3) student participation is reduced in the Wiki environment (Ebner, Kickmeier-Rust, and Holzinger 2008). Finally, the detailed information about student behavior collected by the tracking may allow the teacher to provide specific and precise help to the students or group who are not able to collaborate. We denote the specific and precise help provided to a student having collaborative problems as ***scaffolding***.

Definition – *The tracking and modeling problem in our Wiki environment refers to observing the learners' interactions with the Wiki and other learners to prepare a student model to form groups and to identify scaffolding needs for instructor intervention.*

Our Solution Approach

To solve the group formation and tracking and modeling problem, we use MHCF – a multiagent framework designed based on (Soh and Khandaker 2007). In MHCF, each participating student is assigned an intelligent agent to assist in the group formation. That student agent observes the interactions of its student with the Wiki and the other students and models (1) the student's attributes required for problem solving, and (2) the student's contributions to his or her group. Finally, these agents use an iterative negotiation-based coalition formation process to form student groups—using the students' models and their contributions—that improve the collaborative learning outcome of their members.

Why a Multiagent Solution?

Modeling our proposed solution framework as a multiagent system provides us several advantages that are unavailable in a centralized single-agent framework. Today's collaborative learning theory provides us directions about what type of groups may improve the collaborative learning outcome (e.g., a group that fosters collaboration and knowledge exchange). However, finding the right combination of students with attributes for a given problem in an uncer-

tain and dynamic environment is a computationally expensive problem that requires (1) modeling the impact of students' attributes to their performances as group members and (2) optimizing the distribution of the participating students into disjoint student groups so that each group is able to (a) solve the current task well and (b) encourage collaboration among its members to yield better collaborative learning. Multiagent coalition formation technique allows us to solve this NP-hard problem with intelligent agents who are able to track and model their assigned students and use their *learning abilities* to form better student groups. One issue with this learning is that the learning mechanism or algorithm has fewer chances to observe and model the environment and the participating students. For example, a particular set of students may work together for only a few assignments limiting the modeling agents' observations (e.g., the composition of a group and their collaboration or learning). While using a multiagent-based *divided learning* (Weiss and Dillenbourg 1998) approach, the agents simultaneously observe the environment and models the impact of a groups' members' attributes on its performances. As a result, the agents together are able to help one another somewhat overcoming the limited learning opportunities.

Furthermore, as indicated in a similar educational peer group formation application I-HELP (Vassileva, McCalla, and Greer 2003), a multiagent system is inherently modular, extensible, and allows better scalability than a single centralized agent- or non-agent-based system. For example, in the asynchronous ClassroomWiki environment, whenever a student logs in, we could create an agent that represent that student up and running so that it is able to track and model that student. Furthermore, we could design the behavior of a single agent with simple local decision-making logic (modularity) and add or remove the agent as student log in or out of the system (extensibility).

Agents in ClassroomWiki Architecture

ClassroomWiki is composed of four conceptual modules: (1) Wiki, (2) Communication, (3) Tracking and Modeling, and (4) Group Formation. First, the Wiki module allows the teacher to create and assign Wiki assignments to the students. For students, this module provides (1) revision and (2) versioning of their Wiki assignment text. Second, the Communication module facilitates student and teacher communications through (1) assignment-specific topic-based forums used by the teacher and the student groups and (2) announcements and emails from the teacher to the individual students or student groups. Third, the Tracking and Modeling module contains a set of student agents who are assigned to the participating students to *track* those students' activities in ClassroomWiki to build detailed student *models*. That tracked information is then used to (1) better assess students' individual contributions towards their respective groups' Wiki-related work leading to (a) detection and prevention of free-riding behavior and (b), precise and specific interventions from the teacher to improve collaboration, and (2) better group formation. Finally, the GFM allows the teacher to *automatically* form student groups randomly or by using the tracked student models and the MHCF framework.

Student Agents' Tracking and Modeling

The Tracking and Modeling in ClassroomWiki is composed of a set of student agents where the goal of those agents is to maintain a model of their assigned students according to the Tracking and Modeling principle described above. This student model is based on five categories of tracked student activities: (1) **Active Use**—the actions of a student that push information onto his or her group's Wiki and changes the content of that Wiki; (2) **Passive Use**—student activities in ClassroomWiki that pull information from his or her group's Wiki and do not result in a change in the contents of that Wiki; (3) **Interaction**—a student's interactions with his or her group members while collaborating; (4) **Survey Response**—a student's responses to the various surveys or questionnaires posted by the teacher about the effectiveness of his or her group, peers, or the ClassroomWiki itself; and (5) **Evaluation**—the evaluation scores received by a student for all Wiki-related activities. Assuming is the set of all students and is the set of student agents assigned to those students, Table 1 shows the information tracked by student agent for student .

Note that the student agents calculate the values of the attributes for using the versioning functionality of the WIM. Furthermore, the student agents use Natural Language Processing (NLP) capabilities to compute the values of the attributes for , where the NLP capability of the agents will allow them to build more accurate student models. For example, the NLP capability will allow a student agent to distinguish between: (1) the trivial changes (e.g., spelling correction) and (2) the content-related editions (e.g., addition or deletion of content-related phrases) of its student agent.

Table 1. Information tracked by agent for student *adopted and extended from* (Khandaker and Soh 2009)

Category— Tracked Information
Active Use — (1) Number of words added , (2) number of words deleted for a Wiki revision, (3) number of *content-related* phrases added ; (4) number of *new content-related* phrases added ; (5) min distance between the whole sentences added by and the *whole sentences* added by 's group members ; (6) min distance between the *whole sentences* deleted by and the whole sentences added by 's group members ; (7) number of forum messages posted by to other members' forum topics ; (8) the number of group members' editions the content related phrase added by survives ; (9) the number of group members'

editions the *whole sentences* added by survives ; (10) number of forum topics created ; (11) number of forum messages posted by other group members to 's forum .
Passive Use —Number of times logged in to the ClassroomWiki, length of each ClassroomWiki session, number of times a student views: 1. Wiki assignment specification ; 2. Details of other group members; e.g. email ; 3. Other group member's revisions ; 4. Revision history i.e. list of all revisions and authors of a Wiki ; 5. Other group's revisions (if allowed by the teacher ; 6. Forum topics (a) posted by the student (i.e. to check the messages by other group members, and (b) posted by other group members ; 7. Forum messages posted by other group members .
Interaction —Number of topics created, number of messages posted for own topics and other group member's topics , length of the posted topics and messages in words, number of days the user changed a. the forum i.e., posted forum topics or messages , b. the Wiki, i.e., posted Wiki revisions
Survey Response —Student's evaluation of his or her: (1) Peers, i.e., peer-rating , (2) Group, i.e., team-rating , (3) ClassroomWiki, i.e., Wiki-rating
Evaluation ( )—Teacher's evaluation of a student's a. contributions toward his or her group's Wiki, i.e., Wiki evaluation , b. average performance in other classroom activities or assignments

Using the tracked information described in Table 1, ClassroomWiki builds a student model of a student at time as:

(1)

where (1) denotes the average amount of contribution of a student tracked from his or her Wiki assignments, (2) represents the *collaborative* effort of a student calculated from the summary of that student's collaborative or interactive activities, and (3) represents the average evaluation of a student based on the teacher-assigned grades and peer evaluations. Furthermore, we collapse the different groups of tracked information shown in Table 1 by averaging:

(2)

(3)

(4)

(5)

(6),

(7), (8),

(9)

Here, , and in Eqs. 2-9 are weights. Notice that in Eqs. 2-9: (1) capture the time-averaged performance (e.g., the relative values of the active or passive use) of a student with respect to his or her group and (2) allow the teacher to *customize* the model of a student to better capture his or her performance.

Multiagent Group Formation Framework

ClassroomWiki's Group Formation module allows the teacher to form student groups either randomly or using the Mulitagent Human Coalition Formation (MHCF) framework. Since a detailed description of the MHCF framework is discussed in (Khandaker and Soh 2009), here we only provide a summary.

Given the model of a student, derived from the tracked information discussed in the previous section, a student agent uses the model to first *estimate probabilistically* the contribution of a student towards his or her group's Wiki i.e., his or her performance as a group member. Note that the MHCF framework assumes a probabilistic environment where a student's average performance (as an individual (Eq. 7) and as a group member (Eq. 8)) can be estimated but *not* accurately predicted. Then, based on this probabilistic view of the environment, the agent, on behalf of its user, negotiates with others (1) to collaborate to solve the current task well (improving *the current-task reward* or score) as well as (2) to increase his or her knowledge learned from the collaboration to solve future tasks well (improving the *future-task reward* or score). This is where the tradeoff between the current- and future-task rewards comes into play and the assumption that users learn to improve their problem solving skills from collaborative activities. We further elaborate on MHCF in follows.

Environment – The MHCF framework's environment is denoted as a 5-tuple . Here, is the set of students, is the set of agents where each agent is assigned to a student , is the set of student groups, is a set of tasks which the student groups collaborate to solve, and is a 2-tuple where and are two real-valued functions that estimate the probability of a student's *current-task and future-task rewards* when he or she joins a coalition. Here is defined as (10) and is defined as (11). In Eq. 10 and Eq. 11, is a set of the models (Eq. 1) of the members of the *potential* group at time where that group is being formed to solve the task . Note that the functions and use the *model* of the members of a potential group to calculate the expected current-task and future-task rewards (in terms of evaluations) for a student to if he or she joins that potential group to solve a task. While the current-task reward allows an agent to estimate what its student will receive after participating in a group, the future-task reward is what the agent expects the student will gain in the future, due to their improvement in expertise or behavior through learning. This allows MHCF to look ahead while encouraging students to perform sufficiently well in their current tasks.

Group formation in MHCF occurs in a set of negotiation rounds where in each round, one agent is randomly se-

lected to act as a proposer who negotiates with other agents in the framework to form a group for its assigned student. Once proposed, the proposed-to agent considers its assigned student's model and its current- and future- task reward functions to choose the coalition that provides the highest expected total current- and future- task reward. Once the negotiation rounds end, the agents notify their assigned students about their respective newly formed groups and the details of the task they will collaborate to solve and the collaboration process begins.

Divided Multiagent Learning for Group Formation – Notice that the structure of the formed groups depend upon functions that help the student agents understand how the negotiated composition of a group of students would (1) solve the chosen task and (2) collaborate to learn to solve future tasks better. In MHCF, the student agents *cooperatively* build a Bayesian network (Xiang 2002) (Fig. 1, Fig. 2) that maps a potential student groups' model to their collaborative learning outcome, i.e., *represents* . In this Bayesian Network,

(12) for a student group

. The Bayesian Network is built and maintained using the following steps:

- ***Initialization*** – Initialization is done by (a) setting *uniform priors* – i.e., setting equal current-task and future-task outcomes for all inputs, or (b) using previous performance scores – allowing the teacher to choose previous test scores to initialize the Bayesian Network. For example, as will be discussed later when we discuss the deployment results, the teacher can choose previous test scores that represent the contribution, collaboration, and evaluation aspects of a student and use their average performance scores in the classroom to set the current-task and future-task reward.
- ***Update*** – When the teacher assigns a grade to a group's completed written assignment, that grade becomes the current-task reward node value that group's tracked collaborative interactions (contribution, collaboration, and peer evaluations) are used to calculate the contribution, collaboration, and evaluation nodes. Furthermore, the evaluation scores are inserted as *future-task reward node* values for all previous assignment scores that had the same contribution, collaboration, and evaluation values.

Notice that each student agent is able to observe different student models and thus together *divide the task* (cf. division learning in Weiss and Dillenbourg 1998) of observing the entire set of possible *model-output* combinations. This learning strategy is designed to allow the agents to learn the dynamics of the environment better.

Implementation

ClassroomWiki modules are designed as plain java objects that reside inside a Spring (www.springsource.org) framework and utilizes a MySQL database (dev.mysql.com) as a data repository. Repast (repast.sourceforge.net), an agent-based simulation framework is used to realize the student agents for the MHCF framework. The agents use: (1) LingPipe (Natural Language Processing Tool, alias-i.com/lingpipe) to calculate the values for in Table 1 and *Netica-J* (www.norsys.com/netica-j) to create and maintain the Bayesian Network (Fig. 2).

In our current implementation, we set all weights as equal in Eqs. 2-9. Furthermore, while building the Bayesian Network (in the Update stage) in Fig. 2, we divide the student models' component values (Eq. 7, 8, and 9) into four segments using the quartiles of the distribution of values for an assignment. Furthermore, we used a *sum* as the function in Eq. 12. Since we assume, that a students' model components are not exact, but are probabilistic estimates, this division allows us to efficiently classify each component value. Due to this classification, we are able to build a smaller yet still effective Bayesian Network that allows the agents to capture the probabilistic mapping of a group's members' models to that group's performance.

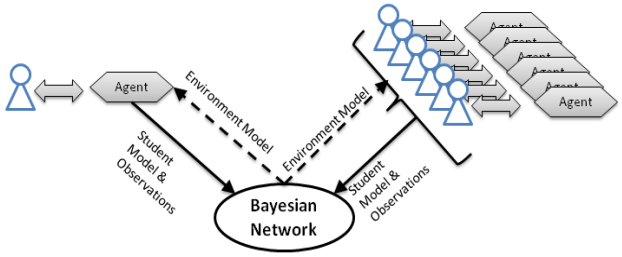

Figure 1: Cooperatively Built Bayesian Network by the Agents.

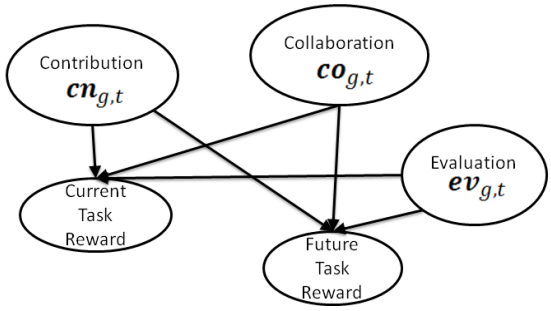

Figure 2: Bayesian Network Structure in MHCF.

Deployments and Evaluation Results

Table 2 summarizes the use of ClassroomWiki in three university-level courses and one community outreach activity. For our HIST 202 and CSCE 475 experiments, we adopted a control-treatment protocol. We divided the students in each deployment into the control and treatment sets based on prior individual student assessment scores—based on assignments assigned to the students prior to the ClassroomWiki activities—such that the average score for each set of students was similar.

Table 2. Deployment Description

Deployment	Time	Experiment
HIST 202 *America after 1877*	(1) Weeks 03/09-04/09 (2) *Ongoing* 10/09	Asynchronous Collaborative Writing
CSCE 475 *Multiagent Systems*	Months 08/09-11/09	Asynchronous Collaborative Writing
ENGL 180 Intro. to Literature	1 Day 10/09	Synchronous Collaborative Writing
GEM	*Ongoing* 10/09	Mentoring Collaborative Writing
WMNS101	*Ongoing* 10/09	Asynchronous Collaborative Writing

HIST 202. In the first deployment, participating students were divided into control ( ) and treatment ( ) sets by following the aforementioned process. The control set students were further divided into groups (5-6 members) *randomly* while the treatment set students into groups (5-6 members) using the MHCF framework. Also, the student models were initialized with previous tests and assignments (as , , and , in Eq. 1). The students then collaborated with their group members to prepare Wiki on "*US as a super power*" topic for three weeks. Then the teacher reviewed each group's Wiki essay and scored each (0-100) and converted each group's Wiki grade to the student members' individual grades by multiplying that group's grade with the relative contribution of that student; i.e., for a student member of group *g* is:

] (13)

where, is 's group grade, for and for are the tracked student activity (Table 1). At the request of the instructor, we are redeploying ClassroomWiki in the Spring semester of 2010 and are expecting to gather more data on ClassroomWiki.

CSCE 475. In this deployment, the participating students were divided into control ( ) and treatment ( ) sets. For initializing the Bayesian Network, the course pre-requisite test scores were used. Then for each collaborative writing assignment, the control set students were further divided into groups randomly while the treatment set students were divided into groups using the MHCF framework. Each student then collaborated with his or her group members on their Wiki assignment writing up on a particular Multiagent Systems topic. After the due date, the teacher reviewed each group's Wiki essay and scored each (0-100). Then the teacher calculated the student grade for a student where is the member of group

(14)

(15)

where, is 's group grade, for are the student activity information tracked by the student agents in ClassroomWiki (Table 1), and is the set of *all* student contribution values in 's group . Note that *both* of our experiment setup was ***double-blind***, i.e., neither the participating students nor the teacher who graded the student groups' Wikis and provided interventions knew which students belonged to the control or the treatment set.

ENGL 180. In this deployment, we used ClassroomWiki to allow the students to collaborate in a synchronous environment to: (1) build Wiki pages and (2) cross link their ideas and concepts on the assigned topics as they built those pages. For the ENGL 180 classroom, the students were assigned to write individual tropes on a variety of literary topics (e.g., Shakespeare – Sonnet 130). As they were writing their individual tropes, they referenced each others' work and cross linked the relevant literary ideas.

GEM. The Girl Empowerment and Mentoring (GEM) for Computing Project aims to inspire middle and high school girls towards computing in post-secondary education by (1) empowering them with skills and interest for IT and (2) mentoring them to improve their self-efficacy and motivation for a career in IT. To help the mentors involved in the GEM project to closely monitor the performance and contribution of the participating students, ClassroomWiki is being used for collaborative writing.

WMNS 101. In this Women and Gender Studies course, we are using ClassroomWiki to investigate the collaborative knowledge building process over time in an asynchronous collaborative writing environment. In this classroom, the students work in groups to define a set of *terms* specified by the instructor over a semester. As they learn the subject matter and attend lectures from distinguished speakers, they are going to modify the definitions of those terms over time. ClassroomWiki is here used by the instructor to (1) form groups that encourage collaboration among their members and (2) track and model the members' activities to gain insights into the collaborative knowledge building process in the groups over time.

Impact of Multiagent Group Formation

Improvement in student scores and Collaborative Interactions. One way to measure how well the agents were able to model the students and form student groups is to compare the performance and collaboration of control and treatment sets. Table 3 shows that the treatment set students achieved *better* scores (higher mean and *lower* standard deviations) than did the control set students (statistically significantly for HIST 202 with). Tables 4 and 5, respectively, indicate that the treatment set students collaborated more (in terms of revisions and forum discussions) than the control set students in HIST 202 and CSCE 475 courses. The ability of the treatment set students' ability to better collaborate and learn could be attributed to

MHCF's ability to form better groups using the Bayesian Network. In HIST 202, the student agents in MHCF formed heterogeneous student groups and resulted in student groups that allowed them to write better quality collaborative essays. In CSCE 475, the student agents were able to observe the students' interactions to iteratively learn how to form better student groups yielding improved student performance and collaboration.

Table 3. Individual and Group Evaluation Scores

Set	HIST 202		CSCE 475	
	Mean	StDev.	Mean	StDev.
Control	70.4	32.9	68.35	30.0
Treatment	74.8	24.7	88.21	13.9

Table 4. Average Revision Count per Wiki Assignment

Set	HIST 202		CSCE 475	
	Mean	StDev.	Mean	StDev.
Control	3.0	2.7	7.0	6.6
Treatment	3.8	3.2	9.1	4.0

Table 5. Average Forum Activity Count per Wiki Assignment

Set	HIST 202		CSCE 475	
	Mean	StDev.	Mean	StDev.
	Forum Topic Count			
Control	2.1	1.4	4.8	2.5
Treatment	2.4	1.8	6.0	5.0
	Forum Message Count			
Control	2.3	2.0	11.6	7.3
Treatment	2.4	1.9	17.5	11.8

Impact of Tracking and Modeling

Alleviation of Free-Riding. The main issues regarding free-riding (Ebner, Kickmeier-Rust, and Holzinger 2008) are: (1) collaborative learning tools do not allow the teacher to accurately capture student's contributions toward his or her group and (2) students do not feel responsible for contributing to their groups. In ClassroomWiki deployments, the agent-based contribution tracking (Eq. 13-15) allowed the instructor to detect the free-riders (13 students in HIST 202 and 3 students in CSCE 475). The instructor was then able to *e-mail* or *meet* with the free-riding students, *before the assignment was over*, to scaffold (motivated them and provided guidance) them to contribute towards their group. Furthermore, for each assignment, the instructor was able to penalize the non-contributing students addressing both issues of free-riding.

Better Assessment of Student Performance. In the HIST 202 deployment, the correlation between the students' Final Exam Score and their ClassroomWiki assignment score was . Furthermore, for CSCE 475, the correlation between the students' average ClassroomWiki assigned score and their Midterm score was . These high correlations suggest that the student agents' model (Eq. 12-13 built with the tracked information in Table 1) of their assigned students' performances *closely represented* the quality of their contributions to their groups.

Increased Student Collaboration. Finally, when the students' participation in ClassroomWiki for HIST 202 is compared (Fig. 4) to those in another Wiki (Blackboard) we see that the students contributed significantly higher (avg. vs. interactions with) throughout the entire period of their collaboration. Unlike Blackboard's Wiki, ClassroomWiki allowed the teachers to accurately track and model the students' contributions to their groups and grade them accordingly. So, this increased student contributions in ClassroomWiki suggests that the accurate tracking and modeling motivated them to contribute more, yielding better collaboration and learning.

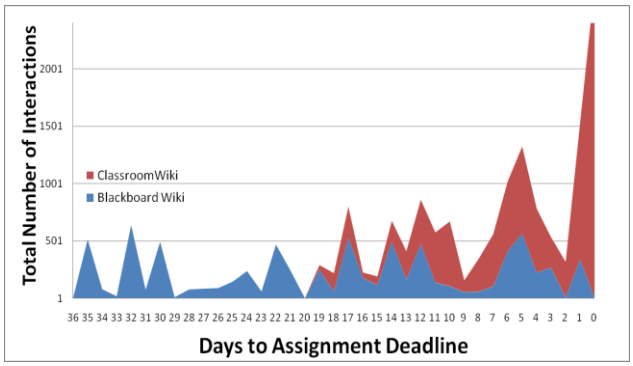

Fig. 4. Students' Use of ClassroomWiki and Blackboard Wiki

User Evaluation of ClassroomWiki

Table 6 shows the students' evaluation of ClassroomWiki environments. The analysis of the students' evaluations reflects that, on average, the students found ClassroomWiki useful. Also, when asked to compare, the students in the HIST 202 course rated ClassroomWiki to be better (avg. 3.4/5.0) than the Blackboard's Wiki. The instructors who used ClassroomWiki in HIST 202 and CSCE 475 also expressed their approval of ClassroomWiki as a useful tool for implementing collaborative writing.

Table 6. Wiki Rating Scores (Likert Scale)

HIST 202		ENGL 180		CSCE 475	
Mean	StDev.	Mean	StDev.	Mean	StDev.
23.4	5.4	23.9	6.65	24.0	4.7

Teacher's Comments for HIST 202. "*I found ClassroomWiki's automated group formation and reliable web-interface to be useful for the students. The contribution tracking was able to provide accurate student contribution information and the captured contribution reflected the improvement effort of the students across all grade levels.*"

Teacher's Comments for CSCE 475. "*Besides automatic formation of student groups, I liked the individual student contribution assessment ability of ClassroomWiki. Using the detailed student activity summaries for an assignment, I was able to accurately gauge a students' con-*

tribution to his or her group and confidently assign grades to the students and proactively intervene in case of the non-contributing students."

Summary

While designing and developing ClassroomWiki we aimed to use agent-based tracking, modeling, and group formation to form student groups that would improve students' collaborative learning outcomes and track and model their performances to better calculate their contributions toward their groups. The analysis of the results of our two main deployments (HIST 202, CSCE 475) suggest that the multiagent tracking and divided learning-based MHCF algorithm allowed the student agents to learn to form student groups that motivated the members to: (1) collaborate more and (2) achieve better quality of group outcomes (i.e., essays). Furthermore, our agent-based tracking and modeling allowed the instructor to better track the students' performances and identify and provide scaffolding proactively. This accurate agent-based tracking also enabled the instructors to catch and penalize free-riding and motivated the students to collaborate more. Although not conclusive, our results suggest that the multiagent-based tracking, modeling, and group formation in ClassroomWiki allowed us to solve two typical problems of collaborative writing.

Conclusions

Here we discuss our ongoing effort to utilize multiagent tracking, modeling, group formation methods to (1) accurately track students' individual collaboration efforts and (2) form student groups that allows them to solve the current task well and solve future tasks well by improved learning. The analysis of the results of our deployments in three university courses suggest that: our use of agent technology allowed us to form better student groups and accurately track and model the students contributions better. Results of our deployments also suggest ClassroomWiki's potential of being used as a collaborative writing tool in synchronous and community outreach classrooms.

We plan to extend the user base of ClassroomWiki by deploying it in other university-level courses. For our future developments, we plan to improve the tracking and modeling in ClassroomWiki by incorporating a user rating system that would allow a student to *evaluate* the members' individual revisions. We also plan to improve the classroom management capability of ClassroomWiki by using our university's user database and allowing the teachers to annotate the submitted Wikis.

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References

Cole, M. 2009. Using Wiki Technology to support student engagement: Lessons from the Trenches. *Computers & Education*. 52(1): 141-146.

Cress, U., and Kimmerle, J. 2008. A systemic and cognitive view on collaborative knowledge building with wikis. *International Journal of Computer-Supported Collaborative Learning*. 3(2):105-122.

Ebner, M., Kickmeier-Rust, M., and Holzinger, A. 2008. Utilizing wiki-systems in higher education classes: a chance for universal access? *Universal Access in the Information Society*. 7(4):199-207.

Forte, A., and Bruckman, A.. 2007. Constructing text: wiki as a toolkit for (collaborative?) learning. In Proc. *International Symposium on Wikis*, 31--42.

Inaba, A., Supnithi, T., Ikeda, M. Mizoguchi, R., and Toyoda, J. 2000. How can we form effective collaborative learning groups? In Intelligent Tutoring Systems, Heidelburg, Berlin: Springer.

Issroff, K. and Jones, A. 2005. Learning technologies: affective and social issues in computer-supported collaborative learning. *Computers and Education*, 44(4): 395-408.

Khandaker, N. and Soh, L.-K.. 2009. ClassroomWiki: A collaborative wiki for instructional use with multiagent group formation. To appear in *IEEE Transactions on Learning Technologies*.

Khandaker, N. and Soh, L.-K. 2010. ClassroomWiki: A Wiki for the classroom with Multiagent tracking, modeling, and group formation. In *Proc. AAMAS*.

Roberts, T. S. and McInnerney, J. M. 2007. Seven problems of online group learning (and their solutions). *Educational Technology and Society*. 10(4): 257-268.

Soh, L.-K., and N. Khandaker. 2007. Formation and scaffolding human coalitions with a multi-agent framework. In *Proc. AAMAS*, 394--396.

Trentin, G. 2009. Using a Wiki to evaluate individual contribution to a collaborative learning Project. *Journal of Computer Assisted Learning*. 25(1):43-55.

Vassileva, J., McCalla, G., and Greer, J. 2003. Multi-Agent multi-user modeling in I-Help. *User Modeling and User Interaction*. 13(1): 179-210.

Weiss, G. and Dillenbourg, P. 1998. What is 'multi' in multi-agent learning? In Collaborative learning. *Cognitive and computational approaches*, Oxford, UK: Pergamon Press.

Wheeler, S., Yeomans, P., and Wheeler, D. 2008. The good, the bad and the wiki: Evaluating Student-Generated Content for Collaborative Learning. *British Journal of Educational Technology*. 39(6): 987-995.

Xiang, Y. 2002. *Probabilistic reasoning in multiagent system - A graphical models approach*. Cambridge, UK: Cambridge University Press.