ClassroomWiki: A Collaborative Wiki for Instructional Use with Multiagent Group Formation

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Abstract—Wikis today are being used as a tool to conduct collaborative writing assignments in classrooms. However, typical Wikis do not adequately address the assessment of individual student contributions toward their groups or provide any automated group formation mechanism. To improve these aspects, we have designed and implemented ClassroomWiki – a Web-based collaborative Wiki writing tool. 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 tracks all student activities and builds detailed student models that represent their contributions toward their groups. For the teacher, ClassroomWiki provides a multiagent framework that uses the student models to form student groups to improve the collaborative learning of students. To investigate the impact of ClassroomWiki, we have conducted a three-week long collaborative Wiki writing assignment in a university-level history course. The results suggest that ClassroomWiki can (1) improve the collaborative learning outcome of the students by its group formation framework, (2) help the teacher better assess a student's contribution toward his or her group and avoid free-riding, and (3) facilitate specific and precise teacher intervention with accurate and detailed tracking of student activities.

Index Terms—Collaborative Learning Tool, Multiagent Systems

1 Introduction

WIKIS today are gaining popularity as a tool for implementing collaborative learning for instructional uses. Recently published examples of such uses of Wiki are described in [1-12]. However, typical Wiki environments are designed to generate informative artifacts (e.g., web pages) through cooperation where the quality of the *generated content* is the focus. However, when used as a collaborative writing educational tool, the quality of the collaboration among the group members is as important, if not more, as the quality of the artifacts generated by the groups. That is because the improvement of students' knowledge and understanding due to learning largely depends on how well they collaborate to exchange knowledge and information with one another [13]. One way to improve the collaboration and thus the collaborative learning outcome of the students in a Wiki is by addressing the important factors that impact the collaboration process of the students [14], e.g., (1) group formation and (2) individual assessment of students.

The method used for forming student groups in a collaborative learning environment impacts the collaboration and the learning of the students because some groups of students are able to collaborate better than others. For example, researchers [14] suggest that forming heterogeneous student groups that combine students with a variety of skills may help them collaborate better. Researchers [14] explain that the improvement in collaboration and learning in heterogeneous student groups occurs since the students with different *perspectives* are able to exchange their ideas and skills with their group members. So, a Wiki that forms heterogeneous groups considering the knowledge and skills of the students would yield better collaborative learning outcomes (e.g., student performance, collaboration) than a Wiki that do not consider these factors. In addition, researchers [14] indicate that accurate assessment of student contributions remains a difficult challenge to overcome in a collaborative learning environment. For example, typical collaborative learning environments often suffer from free-riding phenomenon [14] where some students do not contribute to their group's work but take credit as a group member. This free-riding phenomenon, if left unchecked, may create student antipathy toward collaborative work and reduce collaboration in collaborative Wiki assignments [8]. This means, 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 yielding better collaborative learning outcome. Such improved tracking would also allow the teacher to provide specific and precise interventions proactively which may alleviate problems like free-riding [14].

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However, the typical Wiki tools we have researched [1-12] do not provide any group formation techniques and do not adequately address the assessment of student contributions towards the group. So, to improve the use of Wiki as an educational tool, in ClassroomWiki, we have combined a set of pedagogy theories that explain the collaborative learning process in Wikis with the tracking, modeling, and group formation capabilities of a multiagent framework to design and implement an improved Wiki-based collaborative learning tool. Our ClassroomWiki uses the Multiagent Human Coalition Formation (MHCF) framework (based on the principles described in [15]) to form heterogeneous student groups using the data tracked in ClassroomWiki environment. The novelty of this MHCF framework is in its group formation process which, due to its design and implementation, (1) adapts to the changing behavior of the students and (2) balances the heterogeneity of the members so that a student group contains students of all levels of performances. None of these two aspects are accommodated by the typical Wiki tools (e.g., [1-7]). However, recently published learning theories [13] that describe the collaborative learning process in Wikis suggests that heterogeneity in the performance levels of the members of a student group may improve the collaborative learning outcome in Wikis. Furthermore, since the performance of a student while working on a collaborative Wiki writing activity changes over time, a group formation process that balances the heterogeneity requires an adaptation mechanism that can utilize the change in students' performances to keep forming heterogeneous groups over time.

To test the effectiveness of ClassroomWiki in addressing the group formation and student assessment aspects, we have employed ClassroomWiki in a 3-week long collaborative writing experiment in a classroom with 145 students. The results of this deployment show that ClassroomWiki (1) was able to form student groups which yielded improved student performance, and (2) provided a detailed and accurate view of student activities which in turn allowed the course teacher to (a) more accurately assess a student's contributions, and (b) provide specific interventions when necessary, thereby improving student learning experience.

This paper is organized as follows. In Section 2, we derive a set of design principles from a recently published research work that models the student learning in Wikis. Section 3 describes the ClassroomWiki architecture and the MHCF framework of group formation. Section 4 outlines our implementation while Section 5 describes our experiment setup and results. Finally we conclude with our future work in Section 6.

2 Wiki as a Collaborative Learning Tool

In this section, we discuss a socio-cognitive learning model (proposed by [13]) that explains the student learning process in a collaborative Wiki-based system and discuss how that theory motivates us to incorporate a group formation algorithm and better tracking and modeling functionalities in ClassroomWiki.

2.1 A Model of Collaborative Knowledge Building with Wikis

Cress and Kimmerle [13] 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. They model that coupling or influence with the process of *externalization* and *internalization*. While working in the Wiki environment, learners contribute to topics or create artifacts which they have some knowledge on; which is 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. Furthermore, this internalization interacts with the knowledge a learner already has and produces *emergent* knowledge—that is, knowledge that was neither the part of the externalized artifact nor was possessed by the learner.

So, according to Cress and Kimmerle, individual learning in the Wiki setting results from the interplay between the externalization and internalization processes of the learners and Cress and Kimmerle describe this co-evolution from the interplay of the two processes from the viewpoint of Piaget's model of equilibration [16-18]. This theory proposes that when the environment's knowledge and a person's prior knowledge do not fall in line, it causes a cognitive conflict which can be resolved in two ways, through: (1) assimilation, i.e., by *adding* new congruent information to the prior knowledge or (2) accommodation, i.e., by *modifying* the prior knowledge to better understand the environment's knowledge. So, while interacting with the Wiki, people learn as a result of the internalization and externalization process where this learning takes place due to accommodation and or assimilation occurring in both (1) the learner's cognitive processes and (2) the Wiki. When the learners are merely extending the Wiki by adding information, assimilation is taking place and accommodation occurs when the learners are extending the Wiki and reorganizing the existing information. To what extent these processes occur is determined by the learners' participation in a Wiki, which is also largely determined by their motivation. According to Cress and Kimmerle, this motivation is a function of (1) the incongruity between the learner's knowledge and the information in the Wiki and (2) the valence that Wiki topic has for the learner. The authors mention that a medium level of incongruity [19] and high positive valence [20] yields optimal learner motivation.

2.2 Motivation for Improved Group Formation and Individual Contribution Assessment in Wikis

After discussing the socio-cognitive learning theories and a model that explains student learning in Wikis, we argue that (1) a heterogeneous group formation algorithm and (2) a detailed and accurate individual student contribution assessment mechanism would improve the collaboration and learning of the students in a Wiki.

First, a student group that consists of students with heterogeneous levels of knowledge would bring different *perspectives* on the same assigned topic and would more likely generate cognitive conflicts (mentioned by [13]) than a randomly formed or student-selected group. That increased cognitive conflict would then motivate the students to collaborate (i.e., change the Wiki content) so that the level of incongruity is reduced. That increased collaboration would then improve the participating students' collaborative learning outcome (e.g., the students' performance). Finally, the heterogeneity of the student groups should be balanced in such a way that the difference of the knowledge of the students is not *so large* that it hinders their collaboration [21]. So, a student group with students who have heterogeneous levels of knowledge/ expertise may increase the cognitive conflicts among the students and thus their collaborative learning opportunities and we write the first guiding principle for group formation algorithm as:

Heterogeneity Principle – *The group formation algorithm should balance heterogeneity of learner expertise in a group in such a way that they are less likely to give rise to situations where the participating learners would be demotivated due to too high or too low incongruity between their expertise and the Wiki artifacts they are working on.*

Notice that the heterogeneity among the members of a student group 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 may evolve [22] and their participations in their groups may change [23] as they progress through their syllabus and coursework. Thus, the group formation algorithm has to model those changes and adapt its group formation technique accordingly. Thus we may write our second principle as:

Adaptation Principle – *The group formation algorithm needs to track and model students' activities and performances to capture the changing cognitive states of the students so that it is able to form better groups over time.*

Further, a detailed and accurate tracking of students' activities in the Wiki would also improve student collaboration and learning for the following reasons. First, as pointed out by the CSCL researchers [14], free-riding is one of the main problems in most CSCL environments. This occurs because many CSCL systems do not track and present a summary or model of the students' activities to the teacher which would allow accurate assessment of student's effort. As a result, the free-riding students receive credit without doing any work which *discourages* the hard working expert students from participating in the collaborative activities. Second, the lack of tracking yields lack of accountability for the students and may give rise to occasional irresponsibility which reduces student participation in the Wiki environment [8]. On the other hand, accurate assessment would raise his or her perception of valence since that student can then be held accountable for his or her contribution toward the final quality of his or her group's work. Third, the detailed information about student behavior collected by the tracking may allow the teacher to (1) provide specific and precise help to the students or groups who are not able to collaborate and (2) discover trends and patterns in students' collaborative behavior. Such trends and patterns are important since they have the potential of providing insights into the collaborative process of students leading to improvements in both the process and the environment. Finally, detailed tracking and modeling over time would allow the group formation algorithm to *capture* and *adapt to* the changing knowledge and collaborative behavior in the environment. So, our next guiding principle is:

Tracking and Modeling Principle – *The Wiki should be able to track and present the students' contributions toward their group so that the scores they receive accurately represent the effort they have put in toward their groups' final outcome.*

Although our discussion here motivates the need for a group formation method and better tracking and modeling of students in collaborative Wiki assignment, among the research approaches we have studied [1-12], no one addressed the student group formation based on tracked student behavior in Wikis. However, Trentin [4] addressed the evaluation of the individual student contribution aspect and none of them address the group formation aspect of collaborative Wiki writing. In [4], Trentin combined student activity counts such as the number of messages, with peer reviews to calculate the score of a student. However, that data was manually extracted from the Wiki traces. Such methods are error prone and difficult to implement in large classrooms and inconvenient for the teacher since it generally will require a large amount of work overhead if he or she wants to provide accurate and specific interventions.

3 CLASSROOMWIKI

ClassroomWiki is composed of four conceptual modules (Fig. 1): (1) Wiki (WIM), (2) Communication

(COM), (3) Tracking and Modeling (TAM), and (4) Group Formation (GFM). First, the WIM allows the teacher to create and assign Wiki assignments to the students. For students, the WIM allows: (1) revision and (2) versioning of their Wiki assignment text. Second, COM 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, TAM tracks students' interactions with their group members and with the modules of ClassroomWiki to build a detailed student model. That model is then used to: (1) better assess students' individual contributions towards their 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.

3.1 Wiki Module (WIM)

The WIM allows the teacher to create and assign a topic to the student groups in the course. Once assigned by the teacher, the student groups collaborate to create a Wiki on that topic which is evaluated by the teacher after the due date of the assignment. The WIM consists of the assignment and the versioning component.

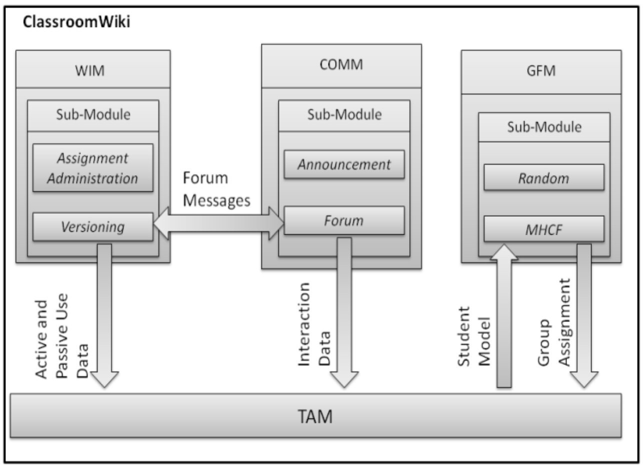

Fig. 1. ClassroomWiki Modules.

The assignment component of WIM allows the Wiki teacher to create Wiki assignments for the participating students. The Wiki assignment specifies the topic, the requirements for the final submitted version (e.g., required sections, word limit, due date), and minimum size of the student groups. Once created by the teacher, the assignment component stores this specification which can then be accessed by the students (while they are collaborating) and by other modules (e.g., the group-size is used by the group formation module).

The versioning component tracks and stores all changes (e.g., addition, deletion) made to the Wiki by all members of each student group. This tracking allows a student to view a *color-coded* (e.g., different colors for additions, deletions, and unchanged text) history of changes of the Wiki made by his or her group members.

3.2 Communication Module (COM)

ClassroomWiki's COM consists of two components: (1) a topic-based forum and (2) an announcement system. The topic-based forum in the COM facilitates the collaboration process of the students in two ways. First, while collaborating, the members of a student group can discuss their plan or approach of writing the Wiki, their revisions, and other Wiki-related questions and comments in the forum. Second, the forum allows the teacher to respond to questions posed by the members of a student group for their Wiki. The announcement system allows the teacher to notify the students about changes or other assignment-specific matters. Furthermore, the forum component supports the four forms of learning mentioned in Section 2.1 by allowing the students to discuss the Wiki assignments with their group members using a topic-based forum. This COM allows the students to discuss any ideas or concepts contained in the Wiki and thus assimilate and accommodate new knowledge from the forum while they are collaborating. Further, while the students exchange knowledge in the forum and resolve their cognitive conflicts through discussions in the forum, the forum itself transforms (i.e., external assimilation and accommodation in Section 2.1) due to those posted discussions. Note that the teacher is also able to participate in a student group's forum where that participation impacts the group's knowledge on the Wiki-topic and thereby enhances the assimilation and accommodation process of that group's members.

3.3 Tracking and Modeling Module (TAM)

The goal of the TAM in ClassroomWiki is to create and maintain a model of every participating student according to the tracking and modeling principle described in Section 2.2. This student model in ClassroomWiki is built using information regarding student activities that can be divided into the following five categories:

(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, e.g., the number of words (1) added, (2) deleted, and (3) rearranged.

(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. For example, the number of times a student views (1) the revision history of their group's Wiki, (2) the topics posted by other group members, and (3) the messages in his or her posted topics.

(3) **Interaction** – a student's interactions with his or her group members while collaborating, e.g., the total num-

ber of topics created, the total number of replies posted, the size of his or her messages in words, and the average number of other group members who replied to a student's posted topic.

(4) **Survey Response** – a student's responses to the various surveys or questionnaires posted by the teacher. These surveys can be designed to capture a student's opinion about the effectiveness of his or her group, peers, or the ClassroomWiki itself. For example, a student may be asked to evaluate the contribution of another group member toward their group's Wiki.

(5) **Evaluation** – the evaluation scores received by a student for all Wiki-related activities, e.g., a teacher's evaluation of a student for his or her contribution for the group Wiki

Assuming $S = \{s_1, \ldots, s_{ns}\}$ is the set of all students in ClassroomWiki, Table 1 summarizes the information tracked by the Tracking and Modeling module for a student $s_i \in S$ in ClassroomWiki. The tracked information in Table 1 is used in ClassroomWiki to build student models that: (1) are used by the Group Formation module (GFM) to realize the MHCF group formation mechanism and (2) allow the teacher to assess the individual contribution levels of students facilitating specific and precise teacher interventions. The details of the use of this stored information are provided in Section 4.

TABLE 1
INFORMATION STORED BY TAM FOR STUDENT s_i

Category— Tracked Information
Active Use (au)—Number of words added (au_i^1), deleted (au_i^2), and reorganized text (au_i^3) for a Wiki revision.
Passive Use (pu)—Number of times logged in to the ClassroomWiki, length of each ClassroomWiki session, number of times a student views: 1. Wiki assignment specification (pu_i^1); 2. Details of other group members; e.g. email name (pu_i^2); 3. Other group member's revisions (pu_i^3); 4. Revision history i.e. list of all revisions and authors of a Wiki (pu_i^4); 5. Other group's revisions if allowed by the teacher (pu_i^5); 6. Forum topics (a) posted by the student (pu_i^6) (i.e. to check the messages by other group members, and (b) posted by other group members (pu_i^7); and 7. Forum messages posted by other group members (pu_i^8)
Interaction (ir)—Number of topics created, number of messages posted for own topics (ir_i^1) and other group member's topics (ir_i^2), length of the posted topics (ir_i^3) and messages (ir_i^4) in words, number of days the user changed a. the forum i.e., posted forum topics ir_i^5 or messages ir_i^6, b. the Wiki, i.e., posted Wiki revisions ir_i^7
Survey Response (sr)—Student's evaluation of his or her: (1) Peers, i.e., peer-rating (sr_i^1), (2) Group, i.e., team-rating (sr_i^2), (3) ClassroomWiki, i.e., Wiki-rating (sr_i^3)
Evaluation (ev)—Teacher's evaluation of a student's a. contributions toward his or her group's Wiki, i.e., Wiki evaluation (ev_i^1), b. average performance in other classroom activities or assignments (ev_i^2)

Using the tracked information described in Table 1, ClassroomWiki builds a model for each of the participating students. The student model $sm_{i,t}$ of a student $s_i \in S$ at time t is defined as a two-tuple:

$$sm_{i,t} = \langle smn_{i,t}, smg_{i,t} \rangle \quad (1)$$

where (1) $smn_{i,t} \in \mathbb{R}$ denotes the average performance of a student as an individual calculated from the tracked information on his or her contributions for the Wiki assignments completed at times, and (2) $smg_{i,t} \in \mathbb{R}$ denotes the performance of a student as a group member calculated by combining the (1) summary of that student's collaborative/ interaction activities for the Wiki and (2) relative individual contribution toward revising the Wiki (calculated by comparing a student's individual contributions with those of the other group members') for Wiki assignments completed at times $t_0 < t$. The two components of the current student model in ClassroomWiki are calculated as the following:

$$\widehat{au}_{i,t} = \left[\left(\sum_{k=1,2,3} waun_k \cdot au_{i,t}^k\right) / \sum_{s_i \in g} \sum_{k=1,2,3} waun_k \cdot au_{i,t}^k\right] (2)$$

$$\widehat{pu}_{i,t} = \left[\left(\sum_{k=1,\ldots,8} wpun_k \cdot pu_{i,t}^k\right) / \sum_{s_i \in g} \sum_{k=1,\ldots,8} wpun_k \cdot pu_{i,t}^k\right] (3)$$

$$\widehat{ir}_{i,t} = \left[\left(\sum_{k=1,\ldots,7} wir_k \cdot ir_{i,t}^k\right) / \sum_{s_i \in g} \sum_{k=1,\ldots,8} wir_k \cdot ir_{i,t}^k\right] (4)$$

$$\widehat{sr}_{i,t} = \left[sr_{i,t}^1 / \sum_{s_i \in g} sr_{i,t}^1\right] (5)$$

$$\widehat{ev}_{i,t} = \left[\left(\sum_{k=1,2} wev_k \cdot ev_{i,t}^k\right) / \sum_{s_i \in g} \sum_{k=1,2} wev_k \cdot ev_{i,t}^k\right] (6)$$

$$smn_{i,t} \propto w_{aun} \cdot \widehat{au}_{i,t} + w_{pun} \cdot \widehat{pu}_{i,t} \quad (7)$$

$$smg_{i,t} \propto w_{aug} \cdot \widehat{au}_{i,t} + w_{irg} \cdot \widehat{ir}_{i,t} + w_{srg} \cdot \widehat{sr}_{i,t} + w_{ev} \cdot \widehat{ev}_{i,t} \quad (8)$$

Here, w_{aun}, w_{pun}, $waun_k$, $wpun_k$, w_{ir}, w_{sr}, w_{ev}, wir_k, wsr_k, and wev_k in Eq. 2-8 are weights. Notice that our design of Eq. 2-6 aims to achieve the following two goals. First, these equations capture the time-averaged performance ($smg_{i,t}$) of a student with respect to his or her group (e.g., the relative values of the active use, passive use, interaction, survey response, and evaluation in Table 1) while working in the ClassroomWiki environment. Second, the weights in this equation allow the teacher to *customize* the model of a student to better capture his or her performance. For example, the teacher may want to adjust the weights to emphasize the importance of peer-rating over the teacher evaluations and student interaction over peer-rating by setting the weights as $w_{irg} > w_{srg} > w_{ev}$. The student model sm_is generated by the TAM is used for the following purposes:

- **To provide better assessment of individual student contribution** – the five categories of student-activity information stored in the student model help the teacher compare the effort or contribution of a student toward his or her group's Wiki against that student's group members' (in accordance to the Tracking and

Modeling principle in Section 2.1). For example, a teacher may compare the total number of words that is added by a student with that of the average number of words added by his or her group members to estimate a student's contribution toward his or her group. This ability to compare the contributions can alleviate the free-riding phenomenon since the students can be held accountable for not contributing to their group's Wiki. However, there could be scenarios where a student could try to game the ClassroomWiki system by, say, adding a large number of useless, trivial words. To counter this, the survey component comes into play. That is, the peer-rating survey results are combined with the quantitative contribution assessment of the students such that a student who tries to game the system would receive a low peer-rating from the group members when they observe the "*unnecessary word-adding*" activity. This issue of improving the assessment of individual contributions, and thus more precise accountability, is further discussed in our future work.

The improved assessment of a student's individual contribution toward his or her group can also be used to prepare a detailed but summarized view of the members of each student group for the teacher so that he or she is able to provide specific and precise intervention if needed. For example, if there are free-riding students in a student group, the information extracted from their models would allow the teacher to conveniently identify (even when classroom size is *large*), intervene, and motivate those students.

- **To improve group formation** – The student models would allow the Group Formation module (GFM) to form student groups that contain a heterogeneous mix of students with varying levels of performances (as an individual (Eq. 7) and as a group member (Eq. 8)), i.e., implement the Heterogeneity principle discussed in Section 2.1. Furthermore, since a student's model is continuously updated, those models will capture the changes in the students' performances (as an individual Eq. 7 or as a group member Eq. 8) while he or she progresses through the Wiki assignments. So, when the GFM forms student groups using the student models, the formed groups will reflect the changes in the students' behaviors thereby implementing the Adaptation principle. For example, if during a Wiki assignment, a student improves his or her knowledge and contribution level toward his or her group, the student's model (i.e., $\boldsymbol{smn_{i,t}}$ ***or*** $\boldsymbol{smg_{i,t}}$ in Eq. 7, 8) would capture that change in terms of improved evaluation scores and increased contribution (forum, revision, etc.). The GFM would then use that changed model to assign the improved student to a different group with a more appropriate level of heterogeneity in future rounds.

3.4 Group Formation Module (GFM)

ClassroomWiki's GFM allows the teacher to form student groups using two different group formation methods: (1) random and (2) MHCF. For random groups, the GFM forms student groups for a collaborative Wiki assignment by randomly choosing the specified number (i.e., according to the minimum group size) of students from the set of all participants in ClassroomWiki. For MHCF, the Group Formation module uses the Multiagent Human Coalition Formation (MHCF) framework (designed based on the principles described in [15]) to form student groups. This framework assigns an intelligent agent to each of the participating students where each agent maintains the model of its assigned student and utilizes that model to (1) probabilistically estimate the contribution of a student towards his or her group's Wiki; i.e., his or her performance as a group member, and (2) negotiate with other agents to form heterogeneous student groups. 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. Based on this probabilistic view of the environment, an MHCF agent, on behalf of its user, negotiates with others to (1) collaborate to solve the current collaborative task well (i.e., improve the current-task reward or score) and (2) improve his or her knowledge through collaboration to solve future tasks well (i.e., improve the future-task reward or score) by forming heterogeneous student groups.

Environment – The MHCF framework's environment E is denoted as a 5-tuple $\langle S, A, G, T, R \rangle$. Here, $S = \{s_1, \dots, s_{ns}\}$ is the set of students, $A = \{a_1, \dots, a_{ns}\}$ is the set of agents where each agent a_i is assigned to a student s_i, $G = \{g_1, \dots, g_{ng}\}$ is the set of student groups, $T = \{t_1, \dots, t_{nt}\}$ is a set of tasks which the student groups collaborate to solve, and R is a 2-tuple $\langle R_{ct}, R_{ft} \rangle$ where R_{ct} and R_{ft} are two real-valued functions that estimates the probability of a student's current-task and future-task rewards when he or she joins a coalition. Here R_{ct} is defined as $R_{ct}: (sm_{g,t}, t_j) \to \mathbb{R}$ (9) and R_{ft} is defined as $R_{ct}: (SM_{g,t}, t_j) \to \mathbb{R}$ (10). In Eq. 4 and Eq. 5, $SM_{g,t} = \{sm_{k,t} | s_k \in g\}$ is a set of the models (Eq. 1) of the members of the potential student group g at time t where the group g is being formed to solve the task $t_j \in T$. Notice that, the functions R_{ct} and R_{ft} use the model of the members of a potential group to calculate the expected current-task and future-task rewards for a student to decide whether he or she joins that potential group to solve a task. The current-task reward here represents the estimated reward a student expects to achieve for the current task for which the group is being formed. Furthermore, the future-task reward here represents the expected reward for the future tasks by learning from the collaborations with his or her group members.

Group Formation – Group formation in MHCF occurs in a set of negotiation rounds where in each round, one agent is randomly selected to act as a proposer who negotiates with other agents in the framework to form a group for its assigned student. The negotiation of an agent is carried out in three steps: proposition, consideration, and notification. The steps are as follows:

- *Proposition* – In the proposition step, the proposer agent chooses $n_{sg} - 1$ other agents (n_{sg} is the minimum group size) and proposes a group which includes the students assigned to those chosen agents. The proposal from an agent a_i to agent a_j is: $P = \langle SM_{g,t}, r_{ct}, r_{ft}, t_j \rangle$ where $SM_{g,t} = \{sm_{k,t} | s_k \in g\}$ is a set of models (not the ids) of the students in the proposed group g, $r_{ct}, r_{ft} \in \mathbb{R}$ are the expected current-task and future-task rewards (Eq. 9, 10) for the task t_j calculated from the perspective of agent a_i.
- *Consideration* – In the consideration stage, the proposed-to agent a_j first compares its model sm_j stored by the proposer agent a_i with its own model of student s_j. If that model is not updated, in other words, if agent a_i is unaware of the recent changes in the model of the student s_j, the responding agent rejects the proposal and sends the updated model of s_j to the proposer. Notice that this notification from the responding agent allows a proposer to have updated view of the other potential members during the coalition formation round. This update procedure is important since each agent is assigned to a single student and may be unaware of the changes in the models of other students. If the proposer has the updated view of the responding agent's assigned student, the responding agent compares the expected current-task and future-task reward values of the proposed group to its current group. The responding agent leaves its current group to join the proposed group if the weighted sum of current-task and future-task reward, is larger for the proposed group g, i.e.,

$$r_{g,t} = \left(w_{ct} \cdot r_{ct,t} + w_{ft} \cdot r_{ft,t}\right) \quad (11)$$

Here, in Eq. 11, the $r_{ct} \in \mathbb{R}$ and $r_{ft} \in \mathbb{R}$ values are calculated by the proposer using the functions R_{ct} and R_{ft} (Eq. 9, 10) respectively. So, in this negotiation process, an agent's decision regarding whether to join a group is determined by the value of these functions. Notice that the number of times this entire negotiation process is run depends on the number of negotiation rounds, which is set as a multiple of the number of agents so that each agent is able to act as a proposer multiple times. Furthermore, to ensure that there is *always* an agreement among the agents, we set the current-task and future-task reward values (Eq. 11) to *zero* if an agent cannot join a coalition (i.e., there is no agreement). Since Eq. 11 yields a non-zero value for any group, there will always be an agreement among the agents since it is better to be in *any* group than to be in *no* group.

- *Notification* – If all of the chosen agents agree to join the proposed group, the proposer sends out a confirmation message to them notifying that they are now in the newly formed group. Otherwise, if any one of the responding agent disagrees, the proposer stops the negotiation process and waits for some other agent's proposal or its next turn to join a group.

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.

MHCF Group Formation and the Design Principles – The MHCF framework forms student groups based on the Adaptation and the Heterogeneity principles. First, with continuous tracking, the agents are aware of the current status of their respective students' models. So, when a student's model changes (say a student becomes more attentive toward the coursework), the assistant agent would be able to adapt to that change accordingly and assign that student to a group that is expected to yield high current-task and future-task rewards. Second, note that the calculation of the expected current-task and future-task reward values are determined by the R_{ct} and R_{ft} functions respectively. In our adoption of the MHCF framework into ClassroomWiki, the teacher can define this function according to the pedagogical strategies that he or she sees fit for the classroom. For example, if the teacher wants to increase heterogeneity in the Wiki assignment groups, he or she may design the functions R_{ct} and R_{ft} in such way that if the models of the participating students indicate that their knowledge levels for the Wiki topic are heterogeneous, the current-task and future-task reward values are high. One such simple design can be implemented in the following manner: (1) let *scg* be the array of average scores of the members of a group g, (2) specify R_{ct} (Eq. 9) and R_{ft} (Eq. 10) functions as: $R_{ct} \propto Avg(scg)$ and $R_{ft} \propto StDev(scg)$. Designed this way, the sum of current-task and future-task rewards (Eq. 11) would be high for groups whose members have high average and standard deviation of scores.

4 IMPLEMENTATION

We have used the open-source, Java-based Spring framework (www.springsource.org) to implement ClassroomWiki as a Web-based system. This implementation allows the teachers and students to participate in collaborative Wiki writing assignments from any computer that has an Internet connection and a Web browser. In our current implementation, the ClassroomWiki modules (WIM, COM, TAM, and GFM) are programmed as plain Java objects that reside in the Spring framework. Here, the Spring framework acts as a container that (1) provides a repository (MySQL, dev.mysql.com) for the ClassroomWiki modules to store and retrieve information described in Table 1 and (2) stores the html WebPages those act as the GUI for the modules. The Spring framework and the ClassroomWiki modules are hosted on a Java Glassfish Application Server (glassfish.dev.java.net) which serves the online user-requests (e.g., access requests from teachers, students) by providing them the html pages generated by the ClassroomWiki modules in the Spring framework. Furthermore, we have used Repast (repast.sourceforge.net), an agent-based simulation framework to realize the agents for the MHCF group formation mechanism in the group formation module (Section 3.4). Deployment diagram in Fig. 2 shows the implementation of ClassroomWiki modules. Furthermore, Fig. 3 shows the typical sequence of steps a student group and the teacher while they are interacting with ClassroomWiki to revise an assignment.

WIM – The current implementation of Classroomwiki in Spring framework provides Web interfaces (html pages) for (a) the teacher to create and assign collaborative Wikis to the students and (b) the students to view their assignment and collaboratively build a Wiki for their group according to the teacher's assignment specification. To facilitate the student's revision of a Wiki, we have embedded TinyMCE (tinymce.moxiecode.com) – a JavaScript word processor into the ClassroomWiki website. The participating students in ClassroomWiki can use this TinyMCE's Microsoft-word-like interface to write and revise their group's Wiki (see Fig. 4)

To implement the versioning functionality (Section 3.1), we have used an open-source Java library called DaisyDiff (code.google.com/ p/ daisydiff) to identify the *added*, *deleted*, and *reorganized* text by comparing the two *versions* of a given html file. For example, for a given original html file, its modified version, and a CSS color code specification file (i.e., the colors of added, deleted, and unchanged words), DaisyDiff can determine the differences between them and generate a diff html file. This diff html file marks all changes (added, deleted, and unchanged words) according to the colors specified in the CSS file making it easy for the students to *visualize* and *comprehend* the changes made by their group members (see Fig. 5). Furthermore, while generating that diff file, DaisyDiff allows the TAM to track the words that were added, deleted, or left unchanged by a revising student.

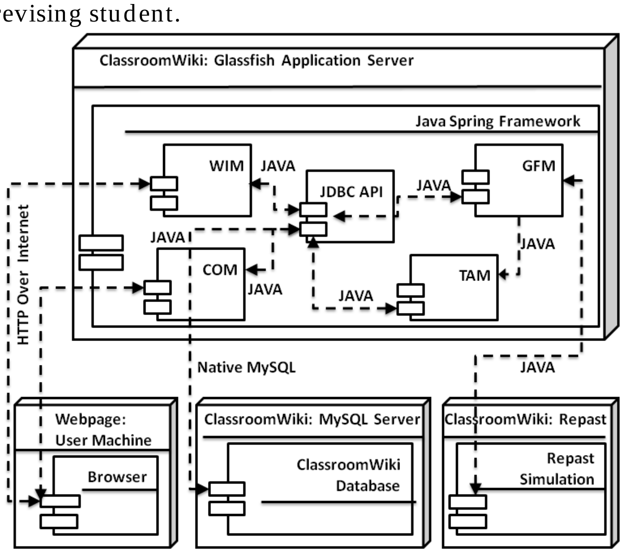

Fig. 2. ClassroomWiki's Implementation Using MySQL Database, Repast, Spring Framework, and Glassfish Application Server.

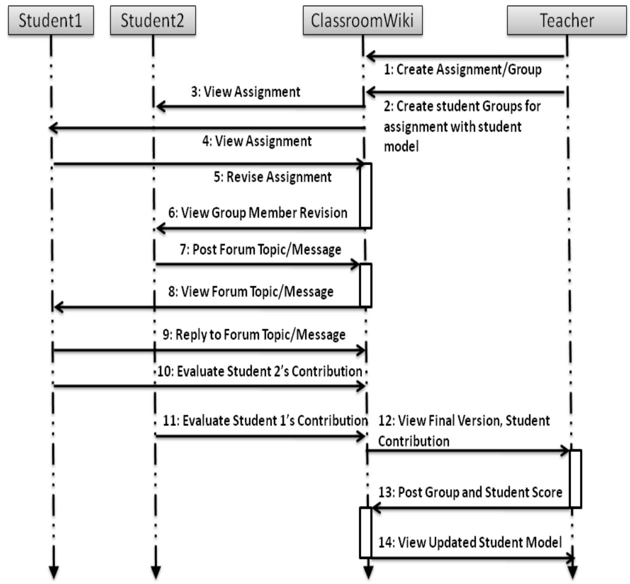

Fig. 3. Sequence Diagram of group members (student1 and student2) and teacher's Interaction with ClassroomWiki System.

COM – The topic-based forum and the announcement system in the Communication module are also implemented as html WebPages using Spring in our current implementation of ClassroomWiki. The webpage for the announcement system (Section 3.2) provides a form to the teacher which allows him or her to write and submit announcements in html which is displayed to all students when they log in to the ClassroomWiki website. In the topic-based forum webpage, the forum messages are categorized according to their topics allowing the students to easily search, read, and respond to the topics/ messages for each collaborative Wiki assignment.

TAM – The TAM is also implemented in Java to collect the student activity-related information (i.e., active use, passive use, survey response, evaluation, and interaction in Table 1) and store this collected information in a MySQL database for other ClassroomWiki modules to use. TAM collects the student-activity related information by using Spring framework's request-driven Model-View-Control (MVC) architecture. Spring's MVC architecture is designed around a central servlet called the dispatcher servlet that acts as a gateway that passes the user requests to the ClassroomWiki modules, collects the result of the processing of the user request from the modules, and then generates the html pages that displays the results to the requesting user.

To track all user interactions in the ClassroomWiki website, we have implemented the *HandlerInterceptorAdapter*, a Java Class written in Spring, that intercepts all incoming user requests processed by the dispatcher servlet. Each request contains (1) the time and name of the requested webpage and (2) all variables associated with the requested webpage and the modules that process that user request. So, using the HandlerInterceptorAdapter, the TAM is able to collect all user activity-related information (au, pu, ir, sr, ev in Table 1) in ClassroomWiki. This collected information is then used by the module to build, store, and update the student models ($smn_{i,t}, smg_{i,t}$ in Eq. 7, 8) in the MySQL database.

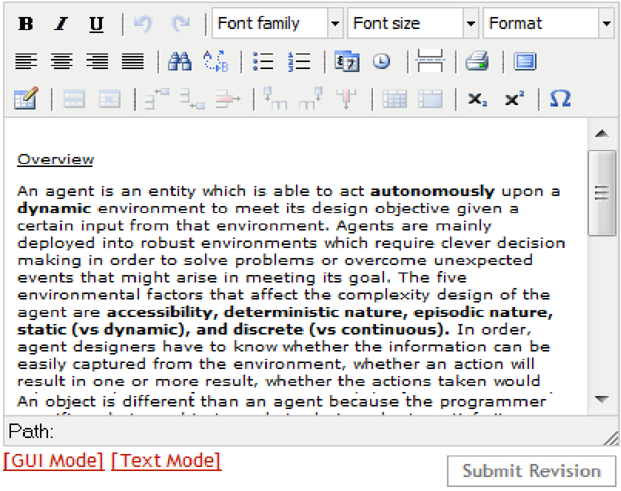

Fig. 4. Resizable TinyMCE Editor for Students.

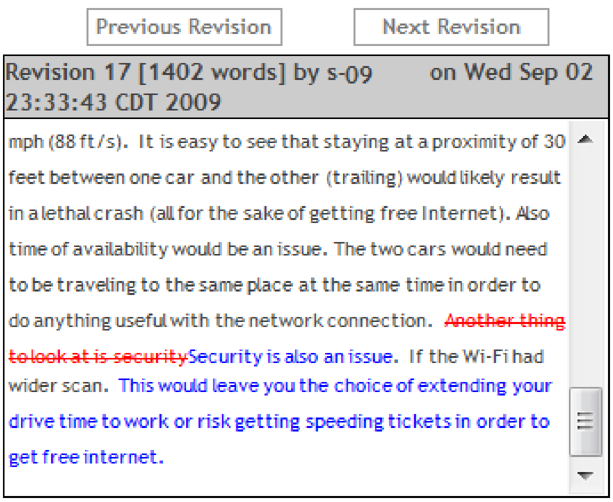

Fig. 5. Revision Viewer in ClassroomWiki.

GFM – To implement the agents that realize the MHCF (Section 3.4) group formation method in the GFM, we have used the aforementieond Repast simulation. When instructed by the teacher, the GFM invokes the Repast environment creating one agent for each of the participating students. Upon initialization, each created Repast agent is provided the updated model of the student it represents. Once initialized, those Repast agents negotiate among themselves to put their assigned students to the groups that provides highest weighted sum of the current-task and future-task rewards (Eq. 11).

As we have discussed in Section 3.4, the MHCF-agents' decision-making relies on the design of the current-task and future-task reward functions i.e., R_{ct} and R_{ft} (Eq. 9, 10). In our current implementation, we have designed these functions to promote the Heterogeneity Principle (Section 2.2). From the perspective of collaborative Wikis, the heterogeneity we would like to promote is the competence of a student as: (1) an individual contributing concepts, ideas, and Wiki-related content to his or her group Wiki, and (2) a group member communicating, collaborating, and working with other members to complete the Wiki assignment. Thus, we use the student model $sm_{i,t}$ (Eq. 1 in Section 3.3) built with the information collected by the TAM to estimate the performance of a student with the following:

$$sp_{i,t} = w_{mn} \cdot smn_{i,t} + w_{mg} \cdot smg_{i,t} \quad (12)$$

where $sp_{i,t} \in [0,2]$ denotes the performance of a student in ClassroomWiki, $w_{mn}, w_{mg} \in [0,1]$ are weights, and $smn_{i,t}$ and $smg_{i,t}$ are from Eq. 7 and 8, respectively. Using this performance value, we design the current-task and future-task reward value functions according to the Heterogeneity Principle (Section 2.2). For a group of students $\{s_i | s_i \in g\}$ with performances $sp_{i,t}\ \forall s_i \in g$:

$$R_{ct} \propto Avg(sp_{i,t}) \quad (13)$$

$$R_{ft} \propto 1/StDev(sp_{i,t}) \quad (14)$$

Here, in Eq. 13, the current-task reward is proportional to the average performance value of the members. That is based on the idea that, when a group contains high-performing students, it is likely that they will be able to solve their current-task, i.e., completing their writing assignment well. Then, in Eq. 14, the future-task reward is inversely proportional to the standard deviation of the performances of the group members. A group that contains students with different levels of performances is more likely to generate cognitive conflicts (Section 2.1) that would motivate them to collaborate/ contribute more to the Wiki and thus improve their performance levels through collaborative learning for future tasks. Thus, in our current implementation, the functions R_{ct} and R_{ft} provides a simple way for the agents to calculate the estimated current-task reward r_{ct} and future-task reward r_{ft} during group formation.

5 Experiment Setup and Results

We have deployed ClassroomWiki in an introductory history course (HIST202 - America after 1877 Section 003) at the University of Nebraska where ClassroomWiki was used to conduct a collaborative Wiki-writing assignment. In the following, we describe the experiment setup. Then, we discuss how useful the students thought ClassroomWiki was as a collaborative learning tool based on survey results. Furthermore, we discuss ClassroomWiki's ability to track more detailed information (i.e., our implementation of Tracking and Modeling principle) than Blackboard's Wiki and that improved tracking's possible impact on the students' collaborative activities. Subsequently we discuss how ClassroomWiki and the MHCF framework's group formation method (designed based on Heterogeneity principle) impacted the collaborative learning outcome of the students. Though not directly measured, we also observe indicators of the impact of the Adaptation principle. Finally, we present how ClassroomWiki's TAM's capability was used by the teacher for intervention and grading students, and could serve to inform redesigning of collaborative writing assignments.

5.1 Experiment Setup

In our experiment, the 145 participating students were divided into control (72 students) and treatment (73 students) sets by sorting the students in an array according to their average evaluation scores (ev_i^2 in Table 1) in the class and then assigning the odd-numbered students to the control and the even-numbered students to the treatment set. This division mechanism was used to *evenly distribute* the high-performing (and low-performing) students between the control and the treatment sets. Once the students were divided, the control set students were further divided into 14 groups randomly while the treatment set students were also divided into 14 groups using the MHCF framework using the GFM. Furthermore, while implementing our group formation algorithm, we have chosen weights $w_{ev} = 1$, $wev_k = 1$, and $w_{aun} = w_{pun} = waun_k = wpun_k = w_{ir} = w_{sr} = w_{ev} = wir_k = wsr_k = 0$ for Eq. (2)-(8) and Eq. (12)-(14).

For the initial ClassroomWiki assignments when we did not have a history of student attributes, to "bootstrap" the system, students' scores from three prior assignments were used: (1) a midterm exam, (2) a collaborative writing assignment, and (3) an individual essay writing assignment. These allowed us to estimate the student performances along three different ability dimensions, i.e., their ability to: (1) comprehend class material, (2) collaborate, and (3) analyze a given essay topic. Since, our agents tried to form student groups that had a high average and high standard deviation; it follows that such a group is likely to have members who are heterogeneous (cf. Heterogeneity principle in Section 2.2) in these three types of skills that are necessary to complete the ClassroomWiki's collaborative writing assignment.

Finally, we acknowledge that when MHCF framework is used, there is thus a bootstrap problem where, for the *first* round of group formation, MHCF does not have a history of student interactions and can only stratify the students based on their previous performances. We will further investigate the impact of this problem using a longer experiment in future (see future works in Section 6).

Once assigned to their groups, each student collaborated with his or her group members to prepare a collaborative Wiki writing assignment on the topic "*US as a super power*" for three weeks. In brief, student groups were first asked to choose a subtopic (e.g., Cuban Missile Crisis 1962) within the general topic by discussing with their group's members using the ClassroomWiki's Forum. Once the subtopics were chosen, the assignments were announced on ClassroomWiki. The student groups then collected and discussed evidences regarding their subtopics and collaborated to write their Wiki essay using ClassroomWiki's WIM. During this process, the teacher periodically monitored the summarized performances (e.g., number of topics or messages posted as described in Table 1) of the student groups and provided group-specific forum messages and emails to help them collaborate better. At the end of the three weeks, the teacher reviewed each group's Wiki essay and scored each (0-100). Then the teacher converted a group's Wiki grade to the student members' individual grades by multiplying that group's grade with the relative contribution of that student. Here, the teacher used the following formula to calculate the student grade ev_i^1 for a student $s_i \in S$ where s_i is the member of group g:

$$ev_i^1 \propto gr_i \times [au_i^1 / \sum_{s_i \in S} au_i^1 + au_i^2 / \sum_{s_i \in S} au_i^2 + ir_i^3 / \sum_{s_i \in S} ir_i^3 + ir_i^4 / \sum_{s_i \in S} ir_i^4 + ir_i^5 / \sum_{s_i \in S} ir_i^5 + ir_i^6 / \sum_{s_i \in S} ir_i^6 + ir_i^7 / \sum_{s_i \in S} ir_i^7] \quad (15)$$

where, gr_i is s_i's group grade, au_i^j for $j = 1,2$ and ir_i^k for $k = [3,7]$ are the student activity information tracked by the TAM in ClassroomWiki and are described in Table 1 in Section 3.3. Note that 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. Furthermore, prior to this study, the students had completed collaborative writing assignments using the Wiki tool on the popular learning management system Blackboard. In our discussions below, we will also compare ClassroomWiki with Blackboard's Wiki.

5.2 Impact of ClassroomWiki

We have conducted a Wiki-rating survey [24] among the students in the HIST 202 class to measure students' view of ClassroomWiki as a collaborative writing tool. The students' responses suggest that on average (mean 22.28 and median 23 on a scale [7,35]) students were satisfied with the performance of ClassroomWiki as a collaborative writing tool. Furthermore, the students preferred ClassroomWiki slightly more (mean 3.4 on a [1,5] scale) than Blackboard's Wiki tool.

Overall Student Performance and Collaboration. Analyzing the "*All*" rows of Table 2 and Table 3 To investigate ClassroomWiki's impact on the collaborative learning outcome of the students, we compare their scores in the ClassroomWiki assignment (All students' evaluation scores in Table 2) with other similar essay assignments (Table 3) and observe that the mean and median student scores in the three essay assignments do not show any clear trends/ patterns. For example, there were no clear indications that the treatment students were better students to begin with. Furthermore, in the ClassroomWiki experiment, the students achieved lower mean and higher median scores than the other assignments except Blackboard's Wiki assignment. However, in Blackboard's Wiki assignment, students' scores were likely to be inflated since Blackboard *does not* allow to the teacher to track individual student contributions (*non-contributing students* in Section 5.3). This comparison suggests that, although some students have always achieved low scores in the tests (and thus produced low averages for the class), while using ClassroomWiki, *some* of those low-performing students have performed *better* when they collaborated with their group members. The improvement of those low-performing students' performances then raised the median score of the students in the ClassroomWiki assignment. In our experiment: (1) ClassroomWiki's collaborative tools (e.g., versioning in WIM, assignment-specific forum in COM), (2) teacher's periodic reminders, and (2) *enforced* accountability of each student's contribution due to our use of TAM could have motivated the students to collaborate with each other to improve the quality of their group's final essay. That improved participation then led to the improved median score.

TABLE 2
STUDENT EVALUATIONS IN CLASSROOMWIKI

Individual Student Evaluation Scores					
Set	**Min**	**Median**	**Mean**	**Max**	**StDev.**
Control	0.00	85.00	70.38	97.00	32.90
Treatment	0.00	83.00	74.84	95.00	24.69
All	*0.00*	*83.00*	*72.62*	*97.00*	*29.05*
Standard Deviation of Group Members' Evaluation Scores					
Control	0.00	34.00	27.40	41.64	-
Treatment	0.80	9.12	15.51	44.63	-

TABLE 3
STUDENT EVALUATIONS IN OTHER TESTS

Set	**Segregation Essay 1/13/09**	**Civil Rights Essay 3/13/09**	**Clicker 4/30/09**	**Midterm 2/27/09**	**Blackboard Wiki 2/27/09**
Control	mn =77.0 md=72.1	mn =70.3 md=75.0	mn =41.2 md=50.0	mn =76.3 md=83.0	mn =75.0 md=85.0
Treatment	mn =75.5 md=78.0	mn =69.3 md=77.0	mn =38.2 md=50.0	mn =76.5 md=77.0	mn =79.2 md=87.0
All	*mn =73.8 md=77.0*	*mn =69.8 md=76.0*	*mn =39.7 md=50.0*	*mn =76.4 md=77.0*	*mn =77.1 md=85.0*

mn=Mean and md=median

5.3 Impact of MHCF Group Formation

Student Scores. The individual and group student evaluations in both the treatment and control sets shown in Table 2 suggest that (1) the treatment set students achieved significantly higher individual scores (higher distribution mean with $p < 0.05$), and (2) the treatment set student groups' achieved significantly lower standard deviations (lower distribution mean with $p < 0.05$) than the control set students. That suggests that the collaboration among the treatment set group members might have been *better* than among those in the control set. This improvement in collaboration could be attributed to the MHCF framework's formation of heterogeneous student groups; i.e., group heterogeneity facilitated more cognitive conflicts and the members learned when they collaborated to resolve those conflicts (Section 2.2).

Student Collaboration. To investigate the collaboration process among the group members in both sets, we have looked at the correlations between the collaborative activities (revisions, forum message postings, etc. as described in Table 1) of the students and their individual evaluation scores (ev_i^1 in Eq. 15) in ClassroomWiki. Table 4 shows the analysis. In Table 4, we see that the treatment set students who achieved higher scores in other classroom assignments (that occurred before the ClassroomWiki experiment) have also achieved higher scores in the ClassroomWiki assignment. However, the same pattern was not observed for the control set students. Furthermore, in the treatment set, the students who performed well in other previous classroom assignments posted relatively more topics and messages to their group's forum. However, in the control set, no such pattern was observed. These observed patterns suggest that the students who achieved high evaluation scores in other classroom activities helped their group members by posting more messages and topics and that those high-performing students were able to achieve relatively higher scores while helping their group members. This can also be explained by MHCF's formation of heterogeneous groups. In the heterogeneous student groups, when the low-performing students' contribution to the group Wiki generated cognitive conflicts (as discussed in the collaborative learning in Wikis in Section 2.1), it motivated the high-performing students to *step in* and help their low-performing group members by posting topics and messages in the group's forum.

Furthermore, Table 5 compares the collaborative activities of the students in the control and the treatment sets. We notice that the treatment set students had a higher count of collaborative activities (except the number of messages). This result combined with the treatment set students' (1) relatively better performance and (2) increased participation of the expert students suggest that the treatment set students' increased collaboration may have helped them to learn from their group members and achieve better scores.

TABLE 4
CORRELATIONS BETWEEN STUDENT ACTIVITY AND INDIVIDUAL EVALUATION SCORE

Variables	**Control**	**Treatment**
Avg. Other Evaluation Score (ev_i^2) and Topic Count (pu_i^6)	0.25	0.49
Avg. Other Evaluation Score (ev_i^2) and Forum Message Count (pu_i^8)	0.25	0.49

Students' Evaluation. We have also compared the control and the treatment set's students' evaluations of their own groups and group members using a Team-Rating survey [24] and a Peer-Rating survey [24]. The results of these surveys suggest that the treatment set students rated their peers (21 vs. 20) and groups (23 vs. 22) only slightly better than the control set students on average. One reason of this non-significant difference could have been that the high-performing students viewed the help they had to provide to their group members as *extra work* and did not rate their groups high. Our analysis reveals that, the correlation between the students' Wiki evaluation scores and the Team-Rating in the treatment set were *higher* (-0.41 vs. -0.27) than the control set students. We need to collect more data to further clarify this issue.

Non-Contributing Students. Table 6 shows the numbers of non-contributing students in HIST 202 class for other previous assignments. We see that, except the first assignment, the treatment set students had more non-contributing students but in ClassroomWiki's assignment, the trend was significantly *reversed*, i.e., more control set students failed to contribute. This again suggests that the treatment set's heterogeneous student groups were more motivated to collaborate and thus had a smaller number of non-contributing students.

TABLE 5
COLLABORATIVE ACTIVITIES OF STUDENTS

Set	# of Revisions	# of Words Added (Revisions)	# of Words Deleted (Revisions)	# of Forum Topics	# of Forum Messages	# of Words in Forum Messages
Control	121	59196	9958	128	601	1673
Treatment	150	62177	13342	134	558	7579

TABLE 6
STUDENT EVALUATIONS IN OTHER TESTS

Set	Segregation Essay 1/13/09	Civil Rights Essay 3/13/09	Clicker 4/30/09	Blackboard Wiki 2/27/09	ClassroomWiki 4/30/09
Control	5	6	4	8	**10**
Treatment	3	7	11	5	**3**

5.4 Tracking and Modeling in ClassroomWiki

Identifying and Penalizing Free-Riding – Although it is difficult to accurately verify, there are positive indications that the student assessment done using Eq. 15 with the data collected by the TAM was able to *capture* the level of individual contributions of the students. In the ClassroomWiki experiment, there were 13 students (10 in the control set and 3 in the treatment set) who did not revise their group's Wiki (i.e., $au_i^j = 0 \; for \; j = 1,2,3$ in Eq. 15) or post any forum topics or messages (i.e., $ir_i^j = 0 \; for \; j = 1, \dots, 7$ in Eq. 15). As a result, their individual student scores were **0**. Furthermore, when compared to the Blackboard's Wiki assignment, we see that there were also 13 students who did not contribute in Blackboard's assignment. However, in Blackboard's Wiki, the teacher was able to catch non-contributing students *only if* the *entire* group of students failed to contribute. In ClassroomWiki, the data collected by TAM allowed the teacher to quickly identify *each individual student's contribution* towards his or her group and penalize that student if his or her contribution fell below the instructor's threshold. Researchers [8] suggest that the main problem regarding free-riding is two-fold: first, often collaborative learning tools do not allow the teacher to accurately capture student's contributions toward his or her group. Second, if the students perceive that their group members are *not* held accountable for free-riding, they feel aversion toward collaborative work. So, the teacher's ability to identify and penalize students who do not contribute towards their groups suggests ClassroomWiki's ability to address both these issues associated with free-riding.

Notice that our assessment of student contributions could have caused game playing among the students where they post revisions to stay ahead of their group members in terms of contribution count/ metric. Although it is difficult to be certain that no game playing occurred in the student groups, our experiment setup was designed to *discourage* such game playing behavior. While presenting ClassroomWiki, we described to the students that the teacher would determine a threshold of student contribution based on the average contribution of the students of the *entire* classroom, then (1) students whose contributions fall *substantially below* that threshold would be penalized and (2) contributing more than average would not yield them extra points. Moreover, students were only able to track their own group members' contributions in ClassroomWiki (and thus would not know of other students' contributions in the class). So, in our experiment, student *motivation* and the *information* that they needed to game the system were both reduced. Finally, researchers [14] have proposed alternate methods of assessing student contributions and free-riding like self-reporting or group signoff of contributions. Although, these assessment techniques could suffer from a different type of problems (e.g., all group members giving good ratings to one another because of previous acquaintanceship) we plan to compare these methods of student assessment with ours as future work (Section 6).

Improved Assessment of Student Performance. We have also found the correlation between the students' Final Exam Score and the score they received for their ClassroomWiki assignment to be 0.75 and that between the Final Exam Score and the Blackboard's Wiki assignment to be 0.51. Treating the final exam in the class as the "ground truth" measuring how much the students have learned, this shows that ClassroomWiki's evaluations can *more accurately* measure—and to some extent predict—students' performances in the classroom than Blackboard's Wiki's. Finally, working with the instructor, ratings of the students' revisions of essays, their forum topics and forum messages have been obtained. The correlation between the sum of the quality of contribution—based on the above ratings—and the students' scores that were assigned following the TAM's model in ClassromWiki is 0.88. This correlation indicates that TAM's model of student performances *closely represented* the quality of their contributions to their groups. Our analysis suggests that ClassroomWiki can effectively *alleviate* a common problem, i.e., the leveling effect, in collaborative learning tools where group members receive the same score even when they don't contribute equally.

Specific and Precise Teacher Intervention – To improve collaborations, the instructor of the HIST 202 course checked the summary of student activities (Eq. 15) and *sent emails* addressed to the whole classroom that praised the groups that contributed and encouraged the groups who needed to contribute more. Furthermore, the teacher monitored the group forums (ir_i^k in Table 1) to assess their progress and posted forum messages to provide *specific* guidance to them.

Adaptation Principle. One of the motivations behind our design of TAM was to help GFM to realize the Adaptation principle (Section 2.2), which consists of: (1) capturing the students' performances and then (2) utilizing the captured student performance to form high-performing student groups. If TAM's captured student model *closely/truly* represents the students' performances, over time, GFM would *keep up* with the change in students' performances and form better student groups. While we agree that to validate that ClassroomWiki realizes the principle would require a long-term experiment (see Section 6), a closer look at our analysis suggests that our implementation is able to realize this principle: (1) TAM is able to closely represent the students' performances and (2) GFM is able to utilize the tracked models to form student groups (Section 5.3) which improve student performance and collaboration.

6 Conclusions

We have presented ClassroomWiki, designed based on the educational research on modeling the collaborative learning process, to improve typical Wiki's functionalities in two aspects: (1) individual student contributions and (2) group formation. While typical Wikis track the changes made by the users, such tracking is from the perspective of the essay and thus *student-centric* statistics are *not* computed and presented *readily*, making assessment based on contributions difficult. Furthermore, typical Wikis do not provide functionalities to automatically form student groups for collaborative activities. Our ClassroomWiki provides a multiagent-based group formation mechanism that uses the tracked student information to form heterogeneous student groups to improve the collaborative learning outcomes of the students. We have reported on a three-week long collaborative Wiki assignment in a university-level history course. Although *not all* results were statistically significant, our analysis suggests that ClassroomWiki may (1) improve the collaborative learning outcome of the students by its group formation framework, (2) help the teacher *identify* and *penalize* free-riding students, and (3) facilitate specific and precise teacher interventions based on the tracked student activities.

Further investigations are necessary to better understand the impact of ClassroomWiki on the collaborative learning outcomes of the students, and our future work thus involves:

- Improving the assessment of the *qualitative aspect* of student contributions in ClassroomWiki by estimating the quality of their edits and messages using natural language processing techniques (LingPipe tool - alias-i.com/ lingpipe) such as: (1) *content-related* phrase identification, (2) sentence detection, (3) stemming [25], and (4) common-words detection.
- Implementing a self-reported and group-reported (i.e., signed off by the group) contribution assessment method. This is to better validate the impact of our current method of student assessment on the free-riding of students.
- Improving the MHCF group formation by incorporating a *Bayesian Network* to enable the agents to learn the current and future task reward functions that map the student models—and learner characteristics—to students' collaborative learning outcomes.
- Obtaining more detailed results for our improved ClassroomWiki by running a more comprehensive, semester-long experiment with a large set of students for multiple collaborative writing assignments. In this experiment we plan to: (1) compare MHCF group formation with VALCAM [26] – another group formation method to provide a stronger comparative baseline, (2) investigate the impact of MHCF on student performance when MHCF is able to utilize the student model built on a more detailed history of student activities, and (3) collect more data to obtain results with higher statistical significance, and to further evaluate the impact of the three design principles.

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