Collaborative and Cooperative-Learning in Software Engineering Courses

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***Abstract*—Collaborative learning is a key component of software engineering (SE) courses in most undergraduate computing curricula. Thus these courses include fairly intensive *team projects*, the intent being to ensure that not only do students develop an understanding of key software engineering concepts and practices, but also develop the skills needed to work effectively in large design and development teams. But there is a definite risk in collaborative learning in that there is a potential that *individual* learning gets lost in the focus on the team's success in completing the project(s). While the team's success is indeed the primary goal of an industrial SE team, ensuring individual learning is obviously an essential goal of SE courses. We have developed a novel approach that exploits the affordances of mobile and web technologies to help ensure that individual students in teams in SE courses develop a thorough understanding of the relevant concepts and practices while working on team projects; indeed, that the team contributes in an essential manner to the learning of *each* member of the team. We describe the learning theory underlying our approach, provide some details concerning the prototype implementation of a tool based on the approach, and describe how we are using it in an SE course in our program.**

I. Introduction

Software engineering (SE) courses in most undergraduate computing curricula include fairly intensive *team projects*. The intent of these projects is to help ensure that students develop the skills needed to work effectively in large design and development teams while, at the same time, develop an understanding of key software engineering concepts and practices as they apply them in completing team project. But there is a definite risk in this approach in that there is a potential that *individual* learning gets lost in the focus on the team's success in completing the project(s). While the team's success is indeed the primary goal of an industrial SE team, ensuring individual learning is obviously an essential goal of SE courses. Before turning to our approach to address this problem, it may be important to clarify the distinction between two terms used to describe learning involving groups of students. *Cooperative learning* is group learning whose main goal is for *every* member of the group to learn to the best of his/her ability. By contrast, the goal of *collaborative learning* is for the group to learn to work together to solve a problem, complete a project, etc.; ensuring that each individual member of the group learns some particular item of knowledge is secondary. Thus the first goal of intensive team projects in SE courses, that of developing students' skills to work effectively in large teams, falls under the rubric of collaborative learning; while the second goal, that of helping students develop deep understanding of SE principles and practices falls under the rubric of cooperative learning[1].

While there has been considerable work on how student teams may be organized, how their meetings should be structured, how responsibilities should (or should not) be divided among the team members, etc., to help with ensuring that the teams function effectively, there seems to be relatively little work on approaches that can help ensure that individual students in team projects such as in SE courses develop a good understanding of the principles and practices that the projects are based on. Indeed, as we briefly summarize in the next section, several researchers have reported that attempts to use *wikis* and the like to have students engage in cooperative learning have been rather ineffective. The main goal of our work is to develop an approach based on classic ideas on how students can help each other learn, a set of corresponding activities that dovetails in a natural manner with typical projects in SE courses to ensure that individual students develop a good understanding of the underlying principles and practices, and to implement a tool that exploits mobile and web technologies in a way that allows students to participate in these activities in an engaging and effective manner.

The main idea underlying our approach may be summarized as *conflict-driven cooperative learning*. The "conflict" here refers to *cognitive conflict* that Piaget explored in his classic work on how individuals learn [11]. Piaget's work showed that when learners engage with *peers* in critical discussion of ideas concerning which they have *different* understandings – this being the source of the cognitive conflict– that contributes effectively to the learner's developing *deep understanding* of the concepts involved since the disagreements with other *learners'* conception of the same idea or topic highlights alternatives to the learner's own conception. The learner is effectively forced to consider and evaluate these alternatives on equal terms. It is critical to note that this is quite different from a *teacher* telling a learner that his or her conception is incorrect because then, given the authority of the teacher, the learner simply accepts it without critical evaluation.

[1]For a more detailed discussion of the distinction between cooperative and collaborative learning, see, for example, Olivares [10]. We should also note that not all authors use these definitions with some authors conflating them and others interchanging the two terms. In any case, there is consensus that there are two types of group activities that students may participate in, with one focusing on maximizing the learning of each student in the group, the other on the group, as a whole, solving a problem or completing a project.

While the potential of cognitive-conflict to drive cooperative learning is clear, what is not so clear is how to overcome the challenge of getting students in SE (or other technical/engineering) courses to engage in activities that will recognize and resolve the conflicts. Students are reluctant to participate for a variety of reasons such as not wanting to be seen as ignorant, not being able to respond on their feet when presented with an idea opposed to their own, instead needing time to formulate a convincing counterargument, not wanting to be seen as assertive, etc. It can be especially difficult to get women students and students from other underrepresented groups to participate effectively in such discussions. In our work, we exploit the affordances of mobile and web technologies to address these challenges. Our approach not only helps address these challenges, it has a number of other important advantages as we will see later in the paper.

In Section 2, we briefly summarize some of the related work. In Section 3, we discuss the details of our approach and our prototype tool that implements it. In Section 4, we describe how we are using it in our SE course and plans for assessing the approach's effectiveness.

II. Related Work

A number of researchers have considered problems that student teams encounter when working on projects similar to those in SE courses and developed ways to address them. For example, one common problem is what is occasionally referred to as *social loafing* or *free riding* in which a student does not contribute to the team's work. For example, Michaelsen and Sweet [9] present what they argue are key elements of team-based learning to help address such problems. Perhaps the most relevant, from our point of view, is *accountability* which requires students be accountable for the quality of their individual as well as group work. One important difference with our work is that the focus here is on assessing the individual student's contribution to the *team*.

Over the years, a number of approaches to using cyber tools to enable cooperative and/or collaborative learning have been developed. CSILE [13] was one of the early systems of this kind. A group of (middle-school) students using CSILE focus on a specified relatively broad problem and begin to build a database of information about the topic. They raise questions, suggest hypotheses, propose possible solutions, and, most importantly, contribute information obtained from outside experts. There is opportunity for reflection and *peer review* by students of each others' contributions. The focus of such systems is on the *group* synthesizing/analyzing knowledge. Thus groups may not only work toward completion of projects as in SE courses but also toward construction of knowledge; this corresponds to the notion of *group cognition* that Stahl [14] presents and he also discusses other examples.

More recently, some authors (e.g., [2]) have proposed using *wikis* to allow users to add, modify, or delete content using a standard browser, to create a site that thoroughly explores a topic. This is similar to CSILE but, as Larusson and Alterman [6] note, "wikis are *plastic*" and can support a variety and range of learning activities and types of interactions among students. Unfortunately, however, wikis have failed to live up to their promise of enabling cooperative learning. Cole's [1] course on *information systems* with 75 students in it was organized so that lectures were in alternate weeks, the other weeks being intended for students to discover new material and post to the class wiki. Fully one quarter of the questions on the final exam were to be from the material that students posted. The expectation was that students would post content, edit each other's posts, and engage in cooperative learning. Halfway through the course there had been *no* posts to the wiki! Leung and Chu [7] report results of the use of a wiki in a course on *knowledge management*. The class was organized into four groups of 4–5 students, each with a leader responsible for coordinating the group's work. Each group had to use a wiki to work on its project. In all of the groups, most of the contributions, in some cases up to 90% of the total, were made by the group leade!. Judd *et al.* [4] report similar findings from a large course on psychology. Although they obtained positive results using wikis in architecture and english composition classes, Rick and Guzdial [12] report that the results in STEM classes were "overwhelmingly disappointing".

In some ways, our approach exploits the plasticity of mobile/web systems. The key difference is that the activities students are required to engage in, as we will see, are designed to trigger cognitive-conflict leading to students engaging in effective cooperative learning, unlike the activities in the above systems where there is little or no structure in the activities.

III. Approach, Prototype System

The idea of having small groups engage in discussions is hardly new. Thus in the *think-pair-share* approach [8], the instructor poses a conceptual question and asks students to think individually about their responses. Then the students pair up with a neighbor and discuss each others' responses. Finally, the instructor calls on some students to share their answers.

Cognitive conflict plays a more central role in the *peer-instruction* (PI) of Mazur [3]. In PI, each student individually answers a conceptual multiple choice question, submitting the answer via a *clicker* or other similar device; then the students turn to their neighbors and, in groups of 3 or 4, discuss the question; after a few minutes of discussion, each student again answers the same question. During the discussion time, the instructor walks around the room but does *not* participate. Mazur reports that the percentage of students who, following discussion with their peers, change their answer from a wrong choice to the correct one far exceeds the percentage who change from the correct choice to a wrong one, demonstrating the power of cooperative learning driven by cognitive conflict. But there are a number of limitations, mostly related to the fact that it is a classroom technique. First, since the multiple-choice question is about the topic discussed in the lecture, students may not have had enough time to think about it deeply. Second, there is no way to ensure that students in a group include ones who picked different possible answers because the grouping is based on where students are seated. Third, some students tend to dominate their groups even if they don't have the right answers. Fourth, the amount of time spent in the discussion is limited; hence, students who take time to formulate their arguments may not contribute effectively.

Our SE course is structured around a semester-long team project with deliverables at specified points. The lectures are synchronized with the project milestones. Thus, for example, in the first two weeks of the semester, class discussion focuses on questions related to the *business context* of an enterprise, considering such questions as how the structure of the industry segment of the enterprise determine its business strategy; of the various things the enterprise might do to improve its competitive position, how it decides what specifically to do; etc. The goal is to highlight that it is only after these questions are addressed that IT can contribute to helping the enterprise become more profitable, by identifying software applications that might be created to support the strategy decided on. The first project deliverable, due about ten days after the class discussion described above, requires each student team to research an actual enterprise $\mathcal{E}$, do a 5-forces analysis of $\mathcal{E}$'s competitive position, consider possible approaches for $\mathcal{E}$ to achieve competitive advantage, develop a portfolio of software applications that $\mathcal{E}$ might create to support the strategy, along with rationale for each application, and identify one of these applications, $\mathcal{A}$, to develop further. Another milestone requires students to do a domain analysis, a problem analysis (for the problem that $\mathcal{A}$ is designed to solve); and a solution analysis for $\mathcal{A}$. The work-products from this step are due about two weeks after the class discussion of concepts related to analysis.

The course uses a *flipped* approach [5]. Lectures are made available on-line which students are expected to watch before the class meetings. The class meeting *starts* with a 15 minute quiz, consisting of *conceptual* multiple-choice questions (like in PI) on the topic; see below for an example. The students are also required to provide rationale for their answer choices. Students may post questions about the topic on the class's electronic forum before the class meeting and the instructor answers them; typically students post no questions. Following the quiz, the instructor presents a summary of the topic. Then picks a few students and asks them to explain their choices; others who made other choices are asked to explain their choices. The intent is that the resulting discussion will help address misconceptions that students may have about the topic.

One problem that is common to students in this course, given that until this point they have primarily worked on designing and implementing systems that have been specified for them, is that they want to start designing and coding the software without going through a careful analysis of the domain, the problem in the context of the domain, etc. Indeed, frequently there is confusion between the domain problem and specific algorithmic or data-structure related problems that might be encountered when developing the software. The quiz below is intended to help identify such misunderstandings.

Quiz 6: Your team has been asked to build a campus wayfinding system to help visually impaired students on campus. Five items identified during analysis are listed belw. Identify which category of analysis –that is, domain, problem, or solution– each element falls under. Briefly explain why.

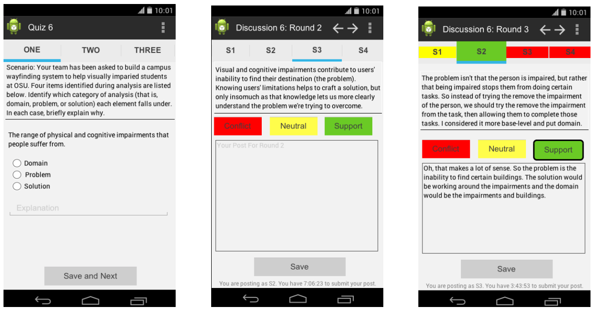
1) A catalog of the various types of building on a campus;
2) The list of hard-to-find buildings on campus;
3) The range of visual and cognitive impairments that people suffer from;
4) Strategies by which people find their way in an unknown area – such as asking passers-by or by identifying major streets.

Item (3) is especially interesting. Many students think it belongs under the *problem* category. But, in fact, it is part of the *domain* because it provides information about the range of impairments people suffer from; the software system is *not* intended to solve the problem of visual impairments (e.g., by developing an artificial eye or something along those lines).

Students come up with different answers for that item and with different justifications. While the class discussion helps clarify the issues for some students, others remain unclear about the distinction between the concepts of domain, problem, and solution. Based on the idea of cooperative learning driven by cognitive conflict, a good approach to address this problem would be to organize the students into groups of 4 or 5 each, with each group including students who proposed different answers, and have them discuss the problem and convince each other of the correctness of their individual points of view. But, for a number of reasons, such a discussion *cannot take place in class*: a) Students in the group need *time* to mull over the arguments of their peers. b) once they have understood the idea/arguments of their peers, they need time to dissect it and see whether they agree with it, disagree with it, or are not sure what to make of it! c) they need time to formulate their conclusion in a manner that is convincing to other group members. And the amount of time needed for each step will vary with the student. d) the class discussion would be ephemeral and a student would not be able to, at a later stage, reanalyze the arguments and counterarguments of the group. Each student could take detailed notes but that is unlikely in the heat of the discussion. e) some students find it difficult to effectively present their ideas, especially if there is a dominating personality in the group.

We have designed a system, *CONSIDER*, that will enable *con*flicting *s*tudent *id*eas to be *e*valuated and *r*esolved (or *r*efuted!). The system will be usable on mobile devices and the web; the prototype runs on (Android) devices. In preparing for a class meeting, after watching the video lecture(s), each student will be be required to submit answers to a quiz that will be available on the *CONSIDER* app. The quizzes will be analogous to the example above but let us assume there is only one question, item (3) from the example. The student will be required to make a specific choice (such as "domain" or "problem" or "solution") and to include a brief *justification*.

Once the students have submitted their answers by a specified time, the system will automatically form groups of 4 or 5 students each with each group containing students who chose different answers[2]. The next time a student logs in, she will be presented with the *discussion space* for her group.



(a) *Quiz* (b) *Discussion* (c) *Discussion*

Each group will have its own space and the identities of the students in a group will *not* be known to others in the group. Instead, students will be named S1, S2, etc. The discussion in G will be organized as a series of *rounds* which we will refer to as $Round_0$, $Round_1$, etc., each lasting for 24 hours. Suppose a group G has four students, S1 through S4. The initial answers submitted by S1 through S4, explaining their multiple choice answers, will constitute the posts for $Round_0$ of G. Each student in G will be required to make exactly one post in in each round. During $Round_k$, S1 will be able to see the posts made by S1–S4 during $Round_{k-1}$; S1 will *not* see the posts made by the other students in $Round_k$ even if some of those posts have already been made. In her post for $Round_k$, S1 will be *required* to pick whether she agrees with, disagrees with, or is neutral about the posts made by each of S1, S2, S3, and S4 in $Round_{k-1}$. She will do this by clicking on a green, red, or yellow button respectively that will be next to the posts from $Round_{k-1}$ of each of S1 through S4. If S1 clicks the red button for any of those posts, a textbox will open in which she will have to provide an explanation of why she disagrees with that post. She will also have the option of providing an explanation if she clicks the green or yellow button.

Thus S1 is *required* to consider the posts made by each student in G in the previous round and analyze its relation to her current position. In fact, S1 has to do this for her *own* post from thar round. This is important because S1 may find the post of one or more of the other students from the previous round so compelling that she changes her mind and no longer agrees with what she said in the previous round! This is the *essence* of cooperative learning driven by cognitive conflict and is highlighted by S1's clicking the red button for her own post from the previous round. S1 may edit her post for this round at any time during the 24-hour period. At the end of the 24 hrs, the round will finish, a new one will begin, and all students in G will be able to see the posts that everyone in G made during the just-ended round. The figure shows screenshots of the quiz (a) and two discussion points (b, c). (b) is from $Round_2$; (c) shows the perspective of S3 in $Round_3$.

[2]If most students make the same choices, the instructor will have to form the groups based on differences in the students' *explanations*. Note also that the groups will *not* (usually) be the same as the project teams.

The discussion will end (typically) after four rounds at which point each student in G will be required to, *individually*, submit a *summary* of the discussion in G and her own *final answer* to the original question. The student's grade for the quiz will depend *only* on this final submission which means that she has to be fully engaged in the group discussion to be successful.

Following this, the project teams will start work on the next milestone of the project; in the current example, this will be the one related to *analysis*. During this period, the team will have access to the final submission of each student in the team. This will allow the team members to further refine their understanding of the concept in question and make use of that understanding in their work on the project. Thus the cooperative learning that took place in the *quiz groups* helps the collaborative work in achieving the project milestone.

IV. Conclusions

We conclude with a brief mention of two items related to our current work and future plans. We are currently working on designing suitable interfaces to make available, to the members of a project team T, the final submission of each member of T. A more conceptual question is the following: suppose T has four members, M1 through M4; should T also have access to the final posts of each member of the quiz groups that each of M1 through M4 belonged to? With respect to evaluation, we plan two prongs: first, we will compare student performance in the final exam of a CONSIDER section of the course with that of a control group; second, we will develop rubrics to compare the projects of teams in the CONSIDER section with those of a control section. This will evaluate the impact on both cooperative learning and on collaborative skills.

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