Using collaborative activity as a means to explore student performance and understanding

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Abstract: This paper presents data from the beginning process of restructuring a usability-engineering course to incorporate aspects of collaborative-process theory with required course content. Students' collaborative processes were evaluated at the end of the semester in order to identify key areas that instructors would need to support better in future iterations of the course. Overall students were skilled communicators, but lacked ability in areas of planning, productivity and critical evaluation. A closer examination was made of difficulties that students had with critical evaluation and trade-off analysis processes since these were key aspects of the course. Findings from analyses were used to suggest ways that the course could be modified in the future to better prepare students to address these important concepts in usability engineering.

Introduction

As more emphasis in technology and science classes gets placed on getting students to do well on product-based outcomes, less emphasis is placed on getting students to understand and engage in important learning processes. This is extremely problematic as researchers and field practitioners in science education have emphasized the growing need for and increasing lack of students' abilities to understand and engage in critical processes associated with collaborative intellectual-activity: the ability to communicate effectively, listen and build on ideas, negotiate ideas, and engage in scientific argumentation (Barron, 2003; Driver, Newton, & Osborne, 2000; Felder, Woods, Stice, & Rugarcia, 2000). Such processes, though identified as critical in educational and work contexts, have been identified as a weakness among American students (SCANS, 1991). The attention focused on collaborative skills has led many schools to increase the number of team-based projects, and collaborative activities they require students to participate in. A fundamental problem with this response is that it assumes that students already possess the cognitive and social skills necessary to engage in effective collaborative endeavors and that these competencies will naturally emerge and develop through exposure to collaborative learning environments; this is wrong. Research has shown that individuals are often frustrated by group interactions, waste time (Salomon & Globerson, 1989), or fall victim to a variety of other problems that lead to dysfunctional group-processes (Webb & Palincsar, 1996). This suggests that students need more explicit guidance with collaborative endeavors than is currently typical.

Gaps in knowledge about what constitutes effective collaborative interactions and/or the ability to apply these concepts in practice are particularly problematic at the college level where individual grades may depend on a team's performance. In The College of Information Sciences and Technology (IST), where our participants have spent the last four years, students are expected to work in teams for much of their academic careers, depending on each other for grades based on their collaborative efforts. Given that dysfunctional interactions among team members can lead to many negative outcomes such as lower performance, alienation, failure, and even the likelihood that students will drop out of the group, the course, even the major (Barron, 2003; Hogan, 1999; Light 1990; Rosser, 1998), it stands to reason that over a four-year time span such trends could lead to considerable problems for these students, and many faculty regularly see these problems play out day-to-day. In order to diminish these problems it is necessary to develop students' collaborative competence. Toward this aim, the authors are currently undertaking a restructuring process for a usability-engineering course in the College of Information Sciences and Technology (IST). The goal for the course is to help students understand and apply important concepts of usability engineering and collaborative-competence theory simultaneously. However, time constraints, the breadth of domain knowledge, and student push back make this an uphill battle. This paper represents the beginning of our journey down Dillenbourg's long road (Dillenbourg & Traum, 1999): moving beyond distribution of the task to a shared understanding of it. The work presented here is a specific report based on one small strand of our research that encompasses a much broader data set.

The usability-engineering course

Usability engineering is defined as the concepts, processes, and practices engaged in the process of developing software systems and applications to ensure that they serve their intended users effectively. To a considerable extent, it mirrors and complements software engineering. Our approach to teaching usability engineering relies on user interaction scenarios as the primary context for analyzing requirements, describing specifications, envisioning designs, developing rationales, creating various sorts of prototypes, and evaluating systems and applications. Our usability-engineering course is organized around a semester-long system development project. The course works its way through a curriculum organized by the flows of the system development process, and student teams define, implement, and test their projects respectively throughout the course. This course has been previously successful with computer and information science students. In 2002, a textbook based on the course was published (Rosson & Carroll, 2002; see http://ist413.ist.psu.edu/ for most recent syllabus and class-by-class activities).

When we designed the usability-engineering course, we carefully devised a list of six main learning goals for our students and came up with various ways that we could implement and assess them (Carroll & Borge, 2007). In this paper we will evaluate students with regards to one of these goals: the ability to build knowledge base through collaborative discussions and refine necessary skills in collaborative groups.

Four core collaborative capacities

Four core capacities within the realm of collaborative learning were identified from educational research literature (Borge, 2007) and unpacked for students. These capacities were intended to embody an organized theory of goals and objectives students would need to meet in order to work in an effective collaborative environment. These capacities were introduced and incorporated into the students' collaborative work. These capacities were originally created as an attempt to structure group processes to address the many factors that can contribute to group-process problems (Borge, 2007; White & Frederiksen, 2000). Originally presented as roles, they were also a useful way to simplify a complex endeavor, such as collaborative interaction, into more manageable sub-skills that students could learn about, demonstrate to each other, and improve upon through practice (Brown & Palincsar, 1985).

The four collaborative capacities are planning manager, communication manager, critical evaluation & negotiation manager, and productivity manager. Physical tools and activities were developed to support the learning and use of the roles/capacities. One of the primary tools was a guide for students that detailed each capacity: the major objectives, problems students may need to prevent/correct, and strategies that they could use to prevent/correct problems (for examples of the guides see http://ist413.ist.psu.edu/, week-to-week activities, calendar, 2/4, under collaborative roles). These Guides were originally developed for children ages 10-14 years of age, but extensively modified for use in this course for use with usability contexts and college age learners. We used feedback from instructors and students to tailor the language, problems, and strategies to specifically address problems faced by this population of students (Borge & White, 2009). Examples of common problems for this population include: improper use of time during team meetings, lack of critical evaluation, and lack of accessibility to collaborative products in real-time. The updated guides included information to prevent and/or correct such problems.

Research methods, objectives, and class context

The research objectives for this project were to fundamentally improve how team activities were implemented, supported and structured in a usability-engineering course so as to improve students' ability to both understand and apply important concepts. Since application of concepts is a critical aspect of the research we will focus on the analyses of an in-class activity requiring the application of usability engineering concepts through particular collaborative interactions. We used assessments of students' collaborative processes from these videos and compared them to their final project grades to see whether students' process performance was correlated to students' performance on their team project.

Participants were students enrolled in a senior level usability-engineering course (IST413). Students were divided into eight teams of five-to-six students: two teams composed of two females and four males and six composed of all males. The teams worked together throughout the semester on collaborative in-class activities, collaborative homeworks, and a semester-long usability-engineering project. All students were required to learn about effective collaborative-interactions, and practice applying goals and strategies during these activities. Students learned about the four capacities, their objectives, and ways of promoting effective collaborative interactions (i.e., setting process goals, and using strategies to prevent or correct team-problems). Goals and activities related to the four capacities were incorporated with 13 in-class activities during which students were expected to work together and turn in a deliverable (an activity worksheet). The activities were either tied to the content covered that week, or to the students semester long project. The roles were a required part of the course since activities, collaborative homework assignments, and even some quizzes required students to practice and understand the roles, their goals and strategies. Students' overall collaborative capacities were assessed from video of teams engaged in an in-class activity in week 13 of the course (for details of the activity see http://ist413.ist.psu.edu/, week-to-week, calendar, activity 13 on 2/28). This videotaped activity was a brainstorming and decision-making session that required students to use and apply concepts they had learned throughout the semester: write design scenarios, identify potential user problems, suggest ways to resolve problems with documentation/help design, evaluate trade-offs of proposed designs, etc. We assessed students on their collaborative interactions by using a scoring rubric developed by Borge, 2009 (See Table 1 for the four capacities and objectives that students were assessed on). This rubric is directly connected with the collaborative-capacity guides as the objectives they assess are those proposed in the guides. Out of eight teams seven consented to be included in our research; these teams were used in analyses. There were five objectives for each of four capacities, for a total of 40 possible points. However, one objective in the planning capacity, and one objective in the productivity capacity were not applicable to this activity (those appear shaded in Table 1). Therefore, there was a total of 38 possible points on this measure.

Table 1: The four capacities and their objectives. Objectives not assessed appear shaded.

Capacities	Objectives
1. Communication	- Most members participate during discussions and quiet members are encouraged to contribute - Team members listen intently - Team members build on each other's ideas - The team works to create a common understanding - Comments are clear, concise, and relevant to the task at hand
2. Planning	- There is a set agenda for the meetings - The team has a long-term plan for the entire project - The team has a set way of providing each other with feedback - The team has set project/interaction goals - The team assigns tasks and responsibilities to ensure that everyone makes equal contributions to the project
3. Critical Evaluation/ Negotiation	- The team considers multiple points of view from various members - The team critiques ideas respectfully and knows difference between positive and negative conflict - The team takes time to evaluate trade-offs of different ideas - The team takes all members into account when deciding which ideas/courses of action to take. - The team keeps track of the ideas that are presented, discussed, and evaluated
4. Productivity	- There is a set method for determining and recording progress - The team does not display off-task behaviors - The team evaluates and works to improve work quality - The team sets time to update each other of their progress - The team turns in high quality deliverables in a timely manner

Students were familiar with the rubrics, as they had used them to assess themselves at the beggining of the semester. When students completed a video-taped activity, at the begining of the semester, they were asked to watch their videos, score their team with these rubrics, and identify areas that seemed particularly problematic for their team. The scoring system was as follows: 0 = does not fuilfill objective to any degree, 1= has some ability to fulfill objective, but still somewhat problematic, 2= fulfills objective perfectly, could be used as ideal example for other students. Once they identified problem areas they were asked to look through the guides and select strategies to prevent/correct the problems they identified. This activity was used as a means to introduce the roles, their guides, and ways to apply the concepts they presented. It was also a means to familiarize students with the rubric we would use to assess their interactions at the end of the semester. At the end of the semester, students were told that we would assess them with the same rubrics they used at the beginning of the semester and we repeated the same procedures as during the first recorded activity.

Reliability of the scoring rubric

The results we report are derived from overall scores determined by the first author. however, we assessed the overall reliability of the scoring rubric by training a graduate student to be a second rater. The second rater was presented with the same materials and guides the students were given. Twenty percent of the data set was doubly coded with the following results: Kappa=.69, and r=0.88, n=140, p< .001. Transcripts were not available at this point in the analysis, so the coding was based directly on video clips. The two coders matched exactly on 78.8 % of the items. Most of disagreement regarded teams for which the first author identified modest critical evaluation (score of 1), but the graduate-student coder felt there was no critical evaluation demonstrated (score -9, n/a).

Transcription of video

Each of the seven 30-minute videos was transcribed following a similar format. Each new speaker utterance and or behavior was numbered, denoting a new “turn”. A “turn” ended when a different speaker introduced a new utterance. The students were given pseudo-names in the transcript. Parentheses were used to label nonverbal gestures and events (i.e., leaving the group, making faces, using hands, etc). Brackets were used for codes, time stamps, and notes relevant to the analyses, but not found in the video itself. These transcripts were utilized when the author scored each team's collaborative interactions with the given rubric, and for microanalysis of processes.

Results

Teams' collaborative interactions: overall findings

Out of 38 possible points in the assessment, the average score across all seven teams was 50% and the median score was 47.3%. This means that all teams scored in the "average" range of performance, getting mainly scores of "1" on the different objectives in the assessment. Scores of "2" were far less common, except in the communication category. Collaborative performance was not significantly correlated to measures of individual performance (i.e., exam scores, class participation, or overall course grade). However, the collaborative assessment was correlated to performance on measures assessed at the team level: where students worked together on one product and shared the same grade (r=.77, p<.05). This suggests that improving collaborative performance could lead to improved performance on deliverables created and assessed at the team level.

When we examined how teams performed on each individual capacity, we found that they performed significantly better on one of them. There was a significant difference between how students performed on the communication capacity (M=.70, SD=.18) and how they performed on the assessment as a whole (M=.50, SD=.13), $t(6)$=6.8, p<.001). Communication was the students' strongest area reflecting strengths in listening for understanding and building on each other's ideas. In fact we saw very little evidence of parallel talk, where one utterance, or turn, is followed by a different and unrelated utterance.

Table 2. Descriptive statistics of teams' overall performance on capacities:
crit = critical evaluation, com = communication, pro = productivity, and plan = planning.

	N	Minimum	Maximum	Mean	Std. Deviation
crit	7	.30	.80	.5143	.19518
com	7	.40	.90	.7000	.18257
pro	7	.25	.75	.4464	.17466
plan	7	.25	.63	.4107	.13909
Valid N (listwise)	7				

There were no significant differences between the rest of the capacities and overall performance with students scoring in the average range for all three capacities. Particular aspects of the planning capacity were not evident in student behavior. For example, students largely accomplished the activity problem by problem, with no thought as to what previous information might be helpful, what the goals of the activity were, or how they would ensure that they achieved those goals. Some aspects of productivity were also missing from students' interactions. Even though they were quite good at staying on task and progressing through items quickly, they still did not perform above average in this capacity. Most of their low scores were due to the fact that they 1) did not show evidence that they had set methods for determining and recording progess and 2) failed to evaluate work quality. Many aspects of this activity depended on students pulling on previous assignments and, for the most part, team members were unaware of who was responsible for which tasks. Failure to evaluate work quality was also a problematic and reaccuring theme. Most teams only cared that the answer was "good enough", not that it was the best possible answer. In fact, student teams actually used the term, "good enough" an average of two times during the activity.

The last capacity we would like to discuss is the critical evaluation/ negotiation capacity. Given that many parts of the activity explicitly asked students to engage in evaluation processes, we would have expected to see higher than average scores in this area, but were disappointed to find that only three teams were able to score any 2s in this area, and only one team fulfilled the trade-off analysis objective, demonstrating the ability to effectively apply the concept of trade-off analysis (a process we will discuss later). All other teams scored 0s on this objective.

Specific problems with the capacity for critical evaluation/ negotiation

Thre was no need for conflict managment or negotiation of differing points of view as students did not seem particularly invested in critiquing or evaluating ideas. Students were very respectful to fellow teammates and there were no instances of intimidation or personal attacks during collaborative activities. Unfortunately, students seemed to be crossing off mental checklists rather than engaging in deeper forms of analyses or argumentation. In fact, students accepted or built upon ideas without stopping to evaluate or challenge those ideas or ask team members to provide rationale for suggestions. Questions, such as, "why do you think we should that" simply were not evident in the team interactions. For the most part, students seemed to lack the ability to step back from problems and evaluate their suggestions as objects of thought. One of the best examples of students' inability to take a step back and think about a problem and its solutions critically came from one of the teams presented below. This particular team was creating a website for a photo club. In this example, the team is working on the second question in the activity.

> *Question 2. Discuss the design scenarios you have prototyped. Choose 2 that you think are most likely to raise problems for learning or use, i.e. where help or other documentation might be required for at least some users. Summarize each scenario briefly, and indicate why you think it might be a candidate for help or training.*

The team (M1, M2, M3, M4, and M5) tries to come up with problems that a user could experience when trying to use their website. Since their website is for a photo club, M3, suggests that they might have problems uploading a picture file. M4 asks M1 to log into the website in order to check for restrictions. M1 tries to log on, but does not remember the password. The rest of the team continues to talk about the potential problem (see Table 3).

Table 3: Team talk as they work to find a solution to a problem in the activity.

1. 00: 20: 24.22 M3: How many picture files can you use?
2. 00: 20: 25.14 M2: It was on the website...
3. 00: 20: 25.25 M1: Yeah where's that at...
4. 00: 20: 33.10 M2: Yeah go to the homepage... yeah, there you go...
5. 00: 20: 35.28 M1: What's the password, anybody...
6. 00: 20: 40.28 M3: Um the other Mike has that, but he's not here... I don't know the password of---
7. 00: 20: 47.13 M4: Why couldn't he make it something easy like one two three four...
8. 00: 20: 49.15 M3: He made it something easy but it was just like---
9. 00: 20: 51.14 M1: Penn State?
10. 00: 20: 52.19 M2: Try it.
11. 00: 20: 54.29 M4: Did he actually send you the---
12. 00: 20: 56.12 M1: No, I just remembered it was something stupid.
13. 00: 20: 57.22 M2: He said it out loud to us.
14. 00: 20: 58.02 M4: Oh... I can't remember!
15. 00: 21: 01.19 M2: Security question?
16. 00: 21: 06.23 M3: Um?... Calendar help training solution, we could just provide like a document that showed you how to do stuff.
17. 00: 21: 26.06 M1: Yeah I'm not sure this is the right, its asking for yahoo ID.
18. 00: 21: 32.05 M3: Even if just [inaudible] the document that shows them where the help is for Flickr.
19. 00: 21: 36.17 M2: That's gonna have a [Inaudible].
20. 00: 21: 37.25 M4: Flickr for beginners?
21. 00: 21: 41.11 M2: Or what happens if you go to the picture page and click on a picture?
22. 00: 21: 50.22 M1: It's asking to, ah, open up.
23. 00: 21: 58.24 M2: [Inaudible] pictures so...
24. 00: 22: 03.05 M1: Um.
25. 00: 22: 07.29 M2: Oh wait.
26. 00: 22: 11.21 M3: What is it?!

The team continues discussing possible problems with uploading pictures in turns 8-11. Meanwhile, M1 still cannot remember the password and asks the team for help (turn 12). In the next 11 turns the team tries to guess the password to no avail. Nonetheless, in turns 25-26, the team marches on, trying to come up with another idea for a problem that a user could experience when trying to use their website, while M1 continues to try to log on. The team proceeded in this manner for two minutes. Unable to resolve the problem and log on, one of the students suggested they simply summarize their previous scenario about a user experiencing problems uploading pictures, but this time add an FAQ or search page to help the user resolve the problem.

What happened here? It seems these students were so engaged in trying to verify a proposed solution to the problem, that they completely ignored the most obvious one: the problem they were experiencing at the moment of not being able to login because no one could remember the password. Forgetting the password is a common problem that many sites simply resolve by allowing you to reset the password. However, for this particular website that solution would not work because all the users share the same password. This was a trade-off that came up in their design, they wanted all the users to be able to link Google Calendars and other aspects of the website to Facebook, but the only way that could work was for all of them to share the same password. This solution gave them want they wanted in a feature without them having to write programming code. However, it had drawbacks as their transcript demonstrated. Identifying these types of trade-offs and thinking ahead for possible solutions was the main goal of the activity, but sadly, not one this team could accomplish. This team was not alone.

Trade-off analysis

Trade-off analysis is a fairly complicated critical-evaluation process that is also a core concept of usability engineering. It involves weighing design goals (i.e., the needs of your users, ease of use, added features, etc.) with constraints and resources of the design team (i.e., cost to build and maintain, programming demands, client demands, etc.) in order to make the most reasonable decisions. Trade-offs, by definition imply that there is no correct answer, just the best one given design goals and resources; it is a balancing of factors that cannot all be attained simultaneously. Given its centrality to this course it was one of the critical evaluation objectives that students were assessed for as part of the collaborative assessment. This was the only objective in the assessment in which teams received zeroes across the board. Only one team, Team 6, was able to effectively apply the concepts inherent to trade-off analysis. This team will be used to illustrate the difference between how the majority of students engaged in the trade-off analysis process, with what was expected.

In question three of the activity, the students were asked to "Analyze trade-offs associated with your design idea. Consider a variety of issues, e.g. cost to build or maintain, generalization to other scenarios, reactions by users, and so on". Six out of seven teams simply responded by coming up with a list of pros and cons. The teams did not justify their design or why it was the best possible solution. They also did not weigh factors involved in their decision making. Instead, team discussions were more akin to identifying possible problems. The following example is representative of the pattern of interactions that stemmed from teams trying to engage in the process of trade-off analysis. In this team, members (M1, M2, M3, M4, and M5) have just completed question two (presented with the example in Table 3) and just now reading question three (see Table 4).

Table 4. Team talk representative of the majority of teams as they worked to resolve Question 3.

1.	00:18:34.05	M1:	can you read the question
2.	00:18:34.07	M2:	It just says analyze the trade offs, consider a variety of situations
3.	00:18:43.29	M1:	[inaudible] ... you can say there is almost no way... if it happens it’s going to come down to the officers of DDF [Dance Dance Fanatics] to do something
4.	00:18:59.02	M3:	Yeah
5.	00:18:59.03	M4:	Yeah
6.	00:19:03.00	M3:	Like when you sign-up you should be required to like... accept---
7.	00:19:08.13	M1:	Like one of those... agreements [inaudible]
8.	00:19:10.29	M3:	yeah, that you always accept and just push ok.
9.	00:19:17.18	M4:	Something with the calendar page
10.	00:19:22.09	M1:	Um
11.	00:19:45.16	M2:	Members using calendar may f[**] it up.
12.	00:19:52.00	M1:	Ha, yes!
13.	00:19:54.21	M3:	He stole the words outta my mouth!
14.	00:20:01.21	M2:	They... what’s a better word than that?!
15.	00:20:07.22	M1:	May not fill in all the field, or something like that.
16.	00:20:08.05	M2:	May hinder---
17.	00:20:10.12	M1:	--- So their, maybe events on there but they may not have like time or place or combination of something or description just be like meeting
18.	00:20:21.17	M2:	Like the date and time.
19.	00:20:22.05	M1:	Might just be ambiguous as to what the person was talking about.
20.	00:20:26.10	M4:	The date is like required.
21.	00:20:28.12	M1:	Yeah its like, you’ll know the day, but its like it might just be completely ambiguous and just say meeting... [inaudible].
22.	00:20:50.28	M2:	I think we're good with three.

In turns 3, 9, and 11, Students present two problems with their design: 1) there is no simple way to monitor content, and 2) users may leave important fields in the calendar page blank. In turns four through nine, students unpack the first problem, and in turns 10-21 students unpack and discuss the second. As students speak a member writes down these problems on their team paper. There is no discussion about alternative designs or justification for why they have chosen this design even though these problems are present. In turn 22 they simply state that they have sufficiently addressed question three and move on to question 4. This was the predominant pattern of talk that ensued from 6 teams during this trade-off analysis portion of the activity: identify problem, agree/build on idea, identify another problem, agree/build on idea, write ideas down and move on. Only one team demonstrated any ability to engage in trade-off analysis, Team 6 (see Table 5 below).

Table 5: Team talk of students demonstrating ability to apply trade-off analysis concepts.

1.	00: 26: 27.22	M2:	Some others, trade-offs.
2.	00: 26: 32.11	M4:	Cost to build or maintain, photo gallery is like it takes time for people to like

3. 00: 26: 41.18 M3: Update their galleries because they have to send them to the administrator and then the administrator has to go and
4. 00: 26: 44.13 M1: Actually (mumble)
5. 00: 26: 47.28 M3: Yeah
6. 00: 26: 47.20 M4: (Mumble) You got a hundred members and all these photos just gonna be taking up space and all that stuff.
7. 00: 26: 55.07 M1: All, well if we get a hundred members [inaudible---all talking at once].
8. 00: 26: 59.24 M4: I don't know how restrictive the university is with all that though.

Conversation continues...

14. 00: 27: 29.03 M4: That's why it has to be each user can just login and upload their own photos
15. 00: 27: 36.09 M2: Cost to build and maintain.
16. 00: 27: 38.08 M4: So that's one of our trade offs I guess, wouldn't it be? Cause ours is like that, and after--- and not so much functional I guess, because of our own time to build something like that with our limited resources.

The patterns of talk are quite different in this team. They begin by identifying a relevant trade-off, cost to build and maintain (turn 22) and then unpack what the trade-off means as it applies to their project (turns2-8). This type of discussion continues as students build on each other's ideas. Until finally, in turn 14, an alternative design idea is proposed that would address their design problems. At which a member reminds them of the trade-off, cost to build and maintain (turn 15) and another team member summarizes their discussion by stating that this is in fact their trade-off: they are settling for a website with vey little functionality because they lack the time and resources to produce anything more complicated. The majority of teams started by identifying problems with their design and never worked their way up to how they fit into a bigger category of trade-offs or thought about how a trade-off category would play out with their project. Team 6 started with a trade-off, worked their way down by unpacking the trade-off as it applied to their system, identified related problems, alternative designs, and then weighed these designs in order to decide which would work best for their team. They did this by summarizing their discussion and defending their original design idea with concrete rationale.

Discussion

Findings from this study have helped us to identify problematic concepts for students and provided us with insights as to how to modify the course in future iterations to address these issues. This course contained a group of seemingly engaged students, who appeared to be collaborating well on the surface. However, when their interactions were closely examined we were able to see that students were falling considerably short of what could be attained in terms of collaborative competence. Students in this course were very competent communicators, but were still lacking abilities to critically evaluate their ideas and work quality as well as plan their work and interactions. We also discovered that students' understanding and practice of the trade-off analysis process is not in keeping with the major goals of the course. Our novice usability-engineering students seem to be making mistakes analogous to Schoenfeld's (1989) novice mathematicians; they were picking solutions to problems and not stopping to evaluate if they were the best ones. Thus we should employ teaching methods similar to those used by Schoenfeld to improve students' critical thinking skills as well as their ability to step back from a problem and think about their performance as an object of thought. Our findings also suggest that we can improve team deliverables (the project score) by improving process learning (their collaborative score).

We are currently developing process-learning activities that can better meet the needs of our students for the next iteration of this course. For example, expert thinking will be made more visible for our students (Collins, Brown, & Newman, 1991) in three ways: 1) the instructor will model trade-off analysis for students with the help of colleagues and focus more on explaining his rationale behind usability decisions by weighing options, 2) students will be shown contrasting examples (such as those presented in Tables 4 and 5) of students engaging in trade-off analysis, and 3) students and instructors will work together on collaborative problem solving activities; the aim being to move to a more discussion centered methodology where evaluation of processes are common topics. We are also trying to minimize the "good enough" tendencies in our students by forcing teams to defend their design ideas during presentations to their peers, and also require peer evaluations of project deliverables throughout the semester. Thus motivating them to focus more on their work-quality and their decision-making processes.

Closing thoughts: the importance of professional collaboration and course evaluation

It is essential for educators to ensure that the collaborative learning opportunities we provide for our students consistently accomplish what we intended them to do: give students opportunities to learn from and challenge the ideas of others, and give them an authentic context to practice applying the core concepts and techniques of a domain. Collaborations between domain experts and experts in the science of learning, such as that between the authors of this paper, are crucial to accomplishing this goal. This type of collaboration is necessary help set appropriate learning goals for students, identify learning goals that present particular problems for students, and implement changes to a curriculum to address these difficulties. Only through these types of collaborations and course evaluations we can fully develop students' learning potential and provide them with richer, more meaningful courses that prepare them to function in an increasingly team-oriented workplace. We do not pretend that these types of domain and process learning fusions do not come with extreme challenges, as we faced many. Among them was a huge push back from students who genuinely felt as though they already knew all there was to know about effective collaborative practice; our finding demonstrate that this is not the case. We contend that the only way to get past students' misconceptions of collaborative practice are to make collaborative goals and processes part of an ongoing conversation between instructors and students that begins in elementary school and continues on throughout their educational and professional careers.

References

Barron, B. (2003). When Smart Groups Fail. *Journal of the Learning Sciences, 12*(3), 307-359.

Borge, M. (2007). Regulating social interactions: developing a functional theory of collaboration. *Dissertation Abstracts International*, 241.

Borge, M., & White, B. Y. (2009). *Scaffolding collaborative processes with managerial roles.* Paper presented at the American Educational Research Association, San Diego, CA.

Brown, A. L., & Palincsar, A. M. (1985). *Reciprocal teaching of comprehension strategies : a natural history of one program for enhancing learning*. Champaign, Ill. Cambridge, Mass.: University of Illinois at Urbana-Champaign; Bolt Beranek and Newman Inc.

Carroll, J., & Borge, M. (2007). Articulating case-based learning outcomes and assessment. *International Journal of Teaching and Case Studies, 1*, 33-49.

Collins, A., Brown, J. S., & Newman, S. E. (1991). Cognitive Apprenticeship: Making Things Visible. *American Educator: The Professional Journal of the American Federation of Teachers, 15*(3), 6-11,38-46.

Dillenbourg, P., & Traum, D. (1999). *The long road from a shared screen to a shared understanding.* Paper presented at the Proceedings of the Computer Support for Collaborative Learning (CSCL) 1999 Conference, Palo Alto, California.

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education, 84*, 287-312.

Felder, R., Woods, D., Stice, J., & Rugarcia, A. (2000). The future of engineering education II. Teaching methods that work. *Chem. Engr. Education, 34*(1), 26-39.

Hogan, K. (1999). Sociocognitive Roles in Science Group Discourse. *International Journal of Science Education, 21*(8), 855-882.

Light, R. (1990). Explorations with students and faculty about teaching, learning, and student life. Cambridge, Mass.: Harvard University Press.

Rosson, M. B., & Carroll, J. M. (2002). *Usability engineering: scenario-based development of human-computer interaction*. San Francisco, CA: Morgan Kaufmann Publishers Inc.

Rosser, S. (1998). Group work in science, engineering, and mathematics: Consequences of ignoring gender and race. *College Teaching, 46*(3), 82-88.

SCANS (1991). *What work requires of schools: A SCANS report for America 2000*. Washington, DC: U.S. Department of Labor.

Schoenfeld, A. H. (1987). What's all the fuss about metacognition. In A. H. Schoenfeld (Ed.), *Cognitive science and mathematics education* (pp. 189-215). Hillsdale, NJ: Lawrence Erlbaum Associates.

Salomon, G., & Globerson, T. (1989). When teams do not function the way they ought to. *International Journal of Educational Research, 13*, 89-99.

Webb, N., & Palincsar, A. S. (1996). Group processes in the classroom. In D. C. Berliner & R. C. Calfee (Eds.), *Handbook of Educational Psychology* (pp. 841-873). New York: Simon & Schuster Macmillan.

White, B., Shimoda, T., & Frederiksen, J. (2000). Facilitating Students' Inquiry Learning and Metacognitive Development Through Modifiable Software Advisers. In S. Lajoie (Ed.), *Computers as Cognitive Tools, Volume Two: No More Walls* (pp. 97-132). Mahwah, NJ: Erlbaum.

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