AC 2009-348: THE COGNITIVE AND MOTIVATIONAL SCAFFOLDING THAT FIRST-YEAR ENGINEERING STUDENTS NEED WHEN SOLVING DESIGN PROBLEMS IN COLLABORATIVE TEAMS

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Cognitive and Motivational Scaffolding First-Year Engineering Students Need When Solving Design Problems in Collaborative Teams

Abstract

This study aims to contribute to the literature on engineering learning by examining the role of team discourse in supporting or hindering first-year engineering students' self-efficacy and achievement. Bandura's self-efficacy theory and Vygotsky's social constructivist theory were used as theoretical frameworks. Twenty-five first-year engineering students (six teams) participated in the study and their team discussions were video and audio recorded between February and May 2007. During the study, students worked on three design projects: a fire rescue project, a pharmaceutical lozenge design project, and a street-crossing problem. A three-stage sequential mixed-methods approach (qualitative → quantitative →qualitative) was used for data analysis. The first and second stages involved the coding of student talk and correlation analyses between self-efficacy, achievement, and discourse type. Results from these two phases were presented in detail in a previous paper. In summary, the analyses showed a statistically significant positive correlation between the amount of *supportive* comments given and the self-efficacy of the giver. There was a negative correlation between self-efficacy and engagement in *disruptive* behaviors. In addition, initial self-efficacy was found to be a predictor of *responsive* behavior. The third step of the data analysis, the focus of this paper, involved an in-depth examination of three case study students (Bryan, a support-oriented student; Eric, a response-oriented student; and Alex, a disruptive student) and their teams. Results suggest that supportive comments can improve self-efficacy and motivation and are critical for collaborative decision-making; however, a lack of analytical argumentation and skepticism can hinder cognitive processes and hurt student learning. As an implication of this study, a list of recommendations is made and an instrument is developed to help scaffold student team processes.

Introduction & Literature Review

Today, more than half of the engineering faculty require their students to participate in group projects (National Science Board, 2008) making pedagogies of engagement such as project-based, problem-based, and team-based learning common practices in engineering classrooms (Smith, Sheppard, Johnson, & Johnson, 2005). When students work in teams they develop diverse knowledge and skills such as the ability to function in teams, learning how to design in teams, and learning new technical content. Consequently, the study of teamwork in the context of science and engineering education has been approached from different directions (See Figure 1).

Some educators focused on the first category, *learning to "work in teams."* Examples of such work are the quantitative studies on factors that affect team effectiveness (Imbrie, Maller, & Immekus, 2005) or qualitative studies based on observations of teams (Adams, Zafft, Molano, Rao, 2008). These studies are generally motivated by the calls of National Academy of Engineering (NAE, 2004; NAE, 2005) and the engineering programs accreditation body (ABET, 2007) suggesting that engineering students need to learn skills beyond the content knowledge. For example, ABET criterion 3d requires that engineering programs can demonstrate that their students have "an ability to function on multidisciplinary teams." Thus, many engineering programs use teaming in their courses as a mechanism to achieve this outcome.

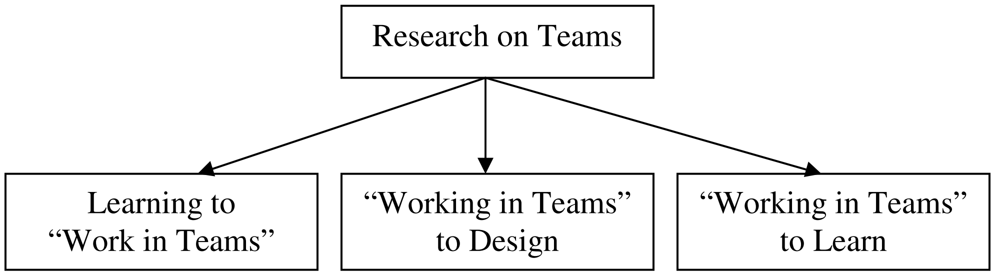

Figure 1. A Typology of Research on Teams

The second research category, "*working in teams" to design* have also been addressed in many studies. These studies have generally used qualitative research methods looking deep into the nature of team interactions (such as design process, team decision-making processes, and team member roles) and how these interactions develop (Tonso, 2007; Cross, Christiaans, Dorst, 1996; Zemke & Zemke, 2008; Yasar-Purzer, Henderson, McKay, Roberts, & de Pennington, 2008).

Other researchers focused on the third category "*working in teams" to learn* and explored how collaborative teamwork support student learning of science and engineering concepts (not teaming and design skills as it is with the previous two categories). Many of these studies have historically shown that collaborative teamwork support learning (Schoeder, Scott, Tolson, Huang, & Lee, 2007; Johnson, Johnson, Halubec, 1998) and are more effective than traditional teaching methods in many ways. However, there is also a growing body of qualitative research studies showing that working in teams does not always lead to learning for all (Taconis, Ferguson-Hessler, and Broekkamp, 2001). These studies report social capital issues that limit students' participation because of their gender, ethnicity, and social status (She, 1999; Southerland, Kittleson, Settlage, and Lanier, 2005; Zeldin & Pajares, 2000).

While we know that students need to develop teamwork skills and that active engagement methods are more effective than the traditional methods in many aspects, our knowledge of how students interact in teams and how these interactions lead to learning is still limited. Therefore, this study aims to contribute to the engineering education literature by examining how students design and learn when they are working in teams.

Theoretical Framework

This study combines two learning theories, Bandura's social cognitive theory (Bandura, 2001) and Vygotsky's social constructivist theory (Vygotsky, 1978), to investigate the nature of student team interaction in the context of engineering. These theories have many commonalities as both define learning as an emergent result of human interactions. A key difference between the two theories is that social cognitive theory is more concerned about learner's internalization process while social constructivist theory focuses more on the scaffolding the learner receives. According to Bandura, learning occurs as an emergent result of a dynamic relationship between human behavior, environment, and human agent (Bandura, 2001). Along with these interactions, self-beliefs are also influential on learning because self-efficacy beliefs translate perceptions of the environment and individual characteristics into behavior (Bandura, 1997; Pajares, 2007). Self-efficacy is one's beliefs about his/her capability to perform a task and can be improved or diminished as a result of social interactions. According to Vygotksy, construction of knowledge is a social process and that learning experiences should expand students' abilities beyond what they can do individually. Vygotksy uses the term, zone of proximal development, which he defines as the distance between what a learner can do alone and his or her potential ability when guided by an adult or more capable peers. In a peer discussion setting, discourse and argumentation can provide learning opportunities within students' zone of proximal development and hence support learning.

Findings from Prior Research

This paper presents the third stage of a larger study that uses a three-stage sequential mixed-methods approach (qualitative → quantitative →qualitative). The first and second stages involved the coding of student talk and correlation analyses between self-efficacy, achievement, and discourse type (Yaşar-Purzer, Baker, Roberts, & Krause, 2008). The goal of the third stage is to further investigate and explain what led to the results revealed through the previous stages of the study.

Results from the previous two stages showed a statistically significant positive correlation between the amount of *supportive* comments given and the self-efficacy of the giver ($R = 0.43$, $p<0.05$). There was also a negative correlation between self-efficacy and engagement in *disruptive* behaviors ($R = -0.48$, $p<0.05$). Furthermore, initial self-efficacy was found to be a predictor of *responsive* behavior ($R = 0.46$, $p<0.05$). However, neither being challenged by peers nor receiving negative feedback revealed significant correlations with student self-efficacy. Finally, no significant correlations were found between any of the team interaction behaviors and student achievement. These findings suggest that while positive team discourse can support self-efficacy, the effect of team interactions on individual student achievement was indirect.

Research Questions

This study investigated the discussions and team interactions of first-year engineering students. More specifically, the research question investigated is: *How do team discourse characteristics and team roles lead to change in self-efficacy and achievement?*

Research Methods

Participants and Data Collection

This research was conducted at a new multidisciplinary engineering program that focuses on collaborative, project-based, and hands-on learning. Twenty-five first-year engineering students participated in this study. These students worked in teams to solve authentic engineering design problems. Teams were formed very carefully and purposefully by their instructors taking students' gender, ethnicity, engineering skills, science backgrounds, and leadership skills into consideration. All teams were composed of three or four members. Two of the teams were mixed-gender and each one included two male and two female members. Students' initial and final self-efficacy scores were measured using an engineering self-efficacy instrument designed in alignment with the course objectives.

Selection of Case Studies
Three students, Bryan, Eric, and Alex (the most supportive, the most responsive, and the most disruptive) were chosen for in-depth analysis. All student names reported in this paper are pseudonyms.

Observations & Video recording
This study was conducted during the spring 2007 semester. The team discussions of seven teams during eight class sessions were observed and audio and video-recorded.

Data Coding & Analysis
The data collected from each team using audio and video-recorders were transcribed. Next, qualitative methods were used for an in-depth analysis of the team interactions. Using interpretive methods, patterns among teams were searched (Erickson, 1986).

Results
A detailed examination of the team interactions and team discourse characteristics of three case study students was the main goal of this study. Table 1 shows the normalized self-efficacy gain scores of the team that the case study students belonged to. Among these three teams, Team B had the highest gains in self-efficacy while Team A had the lowest gains. Team B also had the highest cumulative course grade.

Table 1. Descriptive Statistics for Teams

Case	Team Name	Team Size	Normalized Self-Efficacy Gain of the Team Mean (SD)	Cumulative Team Grade Mean (SD)
Bryan's Team	Team B	4	.46 (.26)	88.32 (5.02)
Eric's Team	Team E	3	.33 (.16)	82.99 (1.21)
Alex's Team	Team A	4	.31 (.22)	87.12 (5.84)

Table 2 shows scores for individuals. Bryan started with the lowest self-efficacy but completed the semester with the highest self-efficacy and cumulative grade. Eric started the semester with the highest self-efficacy score as compared to Bryan and Alex. Alex, on the other hand, had a very small gain in his self-efficacy and completed the semester with the lowest cumulative course grade.

Table 2. Descriptive Statistics for Individuals

Case	Team Name	Pre Self-Efficacy	Post Self-Efficacy	Cumulative Grade
Bryan	Team B	46.88	85.94	92.88
Eric	Team E	79.38	82.50	82.20
Alex	Team A	65.63	68.75	78.96

Bryan: A Support-Oriented Team Member
Bryan's initial supportive comments were short agreements. In Bryan's team, students engaged in disagreements and off-task discussions. However, the team was able to produce effective discussions where agreements were clear. In the following excerpt, Team B is brainstorming

different concepts for the lozenge project. The goal of the lozenge project was to design a procedure to improve the molding process for making personalized drugs. Key constraints of the project included FDA regulations and therefore the team could not make radical changes to the project. Students were given the tools currently used by the pharmaceutical company (a mold and a blade) and teams used wax as the lozenge material. Two questions the team discussed was how to ensure that each lozenge will have equal amounts of wax and how to easily release the wax lozenge from the mold.

B1: Bryan	Heat the blade. That's another possibility.
B2: Brenda	Oh oh, heat the blade.
B3: Barb	… said heat the mold. Heat the mold at a constant temperature.
B2: Brenda	And I am saying cool the mold.
B3: Barb	She wants to stick it in the freezer.
B2: Brenda	(laughs)
B1: Bryan	It's an interesting idea.
B2: Brenda	Like ice cubes

During this discussion, Brenda proposed a new idea, cooling the mold. Barb shows some disagreement with this concept. However, Bryan's comment, "it is an interesting idea", allowed them to maintain a positive team discussion and accumulate as many alternative as possible during their brainstorming process. This was an example of an effective brainstorming process. As the semester progressed, Bryan's comments became more supportive. One of the course activities included an hour-long design problem solving activity on a street crossing problem. Teams were asked to design a safe, simple, and effective solution for a street crossing problem that was occurring on their campus. The following excerpt is taken from the conversation where they were evaluating one of their alternative solutions, hedges of trees, for the street crossing problem. Bryan asked his peers for their input and repeated their ideas, acting as a sound mirror.

B1: Bryan	They die. What's another problem?
B3: Barb	It would be expensive, you want it to be all the way around.
B1: Bryan	Yeah. Could be expensive.
B3: Barb	You did put dying right?
B1: Bryan	Yeah, they die. Allergies.
B3: Barb	Oh, yeah.
B4: Barry	People get allergies?
B3: Barb	Yeah. You can be allergic to the plant.
B1: Bryan	Yeah, the pollen.

Eric: A Response-Oriented Team Member

Eric had the decision maker role in his team. The following excerpt is from a team discussion when they were brainstorming different design concepts for the street crossing problem. Eric's agreements with his team members were short and mostly in the form of "yeah"; however, the fact that his team members frequently sought his approval reflected his decision-making role.

E2: Eddie	Ok. I think. You think we should get going on some design concepts now?
E3: Eric	Sure
E2: Eddie	If we can't think of any more criteria and constraints.
E3: Eric	Yeah
E2: Eddie	To put across
E3: Eric	Yeah.
E1: Elvin	All right so, traffic light
E3: Eric	And then, to improve on that solar power traffic light.
E1: Elvin	Solar… (writing)
E3: Eric	And then just a simple stop light, red light, you stop, no red light you don't.
E1: Elvin	So, solar powered pedestrian?
E3: Eric	Yeah, solar powered pedestrian.

While Eric's team worked very efficiently and engaged in minimal off-task discussions, they did not have a team environment where they made collective decisions. Despite their efficiency and task-orientation, Team E completed the semester with a low mean achievement scores of 82.99 which was below the class mean of 87.46 (SD=4.45).

Alex: A Disruptive Team Member

Alex was a talkative person. When there were disagreements, Alex would defend and insist on his ideas. Very frequently, these arguments would end without resolving the issue. For example, the following discussion occurred when this team was discussing about the fire rescue project at early stages of the semester. Fire rescue project required students to design a device that can be used to rescue a child or a pet during a fire from the second floor of a building. The following excerpt shows Alex's disagreement with Arnold's idea. In this discussion, Arnold proposed using a parachute for the fire rescue device. Alex was opposed to this concept. As seen in the except, Arnold did not want to give up his idea while Alex continued to disagree.

A3: Arnold	Maybe we should put the baby in a parachute.
A2: Alex	No
A4: Azra	No, that's not.
A2: Alex	It wouldn't open enough to slow it down

A3: Arnold	(interrupts) make it really big.
A2: Alex	Right and it wouldn't open up and there is short amount of distance before it hits the ground.
A3: Arnold	What if we put air blows underneath it?

Towards the end of the semester, Alex himself was in the same situation as Arnold. The most negative comments Alex received were when he suggested the birdcage idea for the fire rescue project. The two excerpts provided above and below also show that Team A did not use an effective brainstorming strategy reflecting their professors' instruction. Although students were instructed to be open to new ideas during the brainstorming stage, this team started to evaluate ideas before creating a rich pool of alternative concepts.

A2: Alex	You guys really don't like bird cage idea. I thought it was
A4: Azra	Yeah, but how are we gonna put the baby like? How do you when the baby is really small?
A3: Arnold	I wonder why you are the one who suggested to put it in the bird cage?
A4: Azra	You don't think it's gonna hurt him?
A3: Arnold	Perhaps some childhood
A2: Alex	That wouldn't hurt him. That's literally kind of like xx. We modify the inside of the birdcage so it can.
A4: Azra	So, what are you thinking of doing inside of a cage? Do you have any idea?
A2: Alex	I don't know put in something like a xx something side supports.

The birdcage idea was strongly rejected by Alex's team members. Nevertheless, he defended his ideas. Overall, within Alex's team, a harmony did not exist. Alex's behavior became more disruptive and less supportive as the semester progressed.

Discussion

The team discourse and experiences of Bryan, Eric, and Alex show that students work and interact in diverse ways when they work in teams. Eric was the decision-maker in his team. His team members showed disagreements with his comments but did not challenge his decisions. In Alex's team, there were constant arguments and they never reached a group consensus. Bryan's team was able to balance supportive behavior and skepticism; which he orchestrated very effectively. Among these three teams, Bryan's team had the highest gains in self-efficacy while Alex's team had the lowest gains. Eric's team had the lowest cumulative course grade although they never engaged in off-task discussions.

The argumentative dynamics of Alex's team that became apparent very early during the semester. Alex had the lowest post self-efficacy compared to the other case study students and the lowest cumulative grade in class. This shows that team interactions can influence students' self-efficacy. In Team B, Bryan had a significant influence on the development of a positive team atmosphere. Bandura's self-efficacy theory supports this claim. Team B also had arguments and discussions when they had disagreements. In Team E, discussions were focused on the task but did not include any significant supportive social interactions. In addition, key decisions were made without team discussions. This finding suggests that a complete lack of argumentation is also problematic because students need opportunities to challenge each other's ideas and co-construct knowledge together. Vygotsky's social constructivist theory and other studies on scientific argumentation and collaborative learning also support this claim (Kittleson & Southerland, 2004; Oliveria & Sadler, 2008).

Classroom Applications

As an implication of this study, I developed an instrument to help scaffold student team processes so that students can be skeptical of ideas (e.g., request evidence) but at the same time be supportive of their peers (e.g., acknowledge contributions). This instrument is called a MERIT card (Methods for Evaluating Roles and Interactions in Teams) and shown in the appendix. The questions on this card reflect areas of common weaknesses observed when students work in teams. This card has the dimensions of a bookmark and can be used in class following team activities for students to reflect on their strengths and weaknesses and make process adjustments when necessary. It is important to note that this card is not designed to grade students or for the purpose of peer evaluations. The main objective in using this card is to teach students to be cognizant of their own team interactions. The card can also be used by the instructors for observational purposes to provide immediate feedback to the teams.

Recommendations for Future Research

The use of both social cognitive and social constructivist theories is essential when studying engineering student team interactions. I suggest that further research investigate the reciprocal relationship between analytical (i.e. skeptical) and supportive discourse that improve student learning and motivation in collaborative team contexts. Further research should also explore questions such as: Is it possible to predict individual student team member discourse characteristics before forming teams? How much of the individual team role characteristics emerge as a function of the team members and how much of the individual characteristics stay the same regardless of the team a student is assigned to? What are effective ways to gather such information and help teams work more effectively?

Acknowledgments

I would like to thank all of the student participants and their teachers for helping me realize this research.

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Appendix. MERIT Card

	MERIT CARD
***G**oal Actions*	*Did the team establish a common understanding of the goals in the beginning and refer back to goals for clarification during the meeting? -Did the team establish a timeline in the beginning, track the time, and make process adjustments when necessary?*
***R**elationship Actions*	*-Did everyone have a fair opportunity to participate and were everyone's ideas considered? - Did the team acknowledge contributions, hard work, and good ideas, and show gratitude towards each other?*
***L**earning Actions*	*Did the team develop new understandings through discussions of new information obtained from each other and external resources? -Did the team use visual representations (pictures, charts, models) and examples to communicate ideas to each other?*
***C**hallenge Actions*	*Did the team identify possible challenges and discuss how they can be tackled? -Did the team make decisions based on data, evidence, calculations, and a systematic evaluation rather than opinions?*