AC 2010-1902: TEAM-BASED NEGOTIATION OF IDEAS ON DESIGN DECISION MAKING PERFORMANCE

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Introduction

Engineering in the 21st century is becoming a more social process with multiple stakeholders. Nowadays, many engineering design projects are undertaken by project teams consisting of various disciplinary content experts. This type of engineering work requires domain knowledge coupled with many professional skills such as teamwork, collaboration, communication of ideas, decision making, etc. Recent reports such as the Engineer of 2020[1] have recognized that such skills are essential in the education of the next generation of engineers. The challenge is finding effective instructional methods that develop these skills without large amounts of instructional overhead.

Engineering instructors often utilize project based design courses to engage and develop many of the professional skills students will need in the workplace. Although students are exposed to teamwork in their engineering curriculum, it is not the most dominant mode of their learning experience. Students may encounter difficulty in communicating and negotiating their ideas with team members unless they are given tools and strategies to support the process. They also need multiple opportunities to engage and use these methods as part of their curricular experience so they are better prepared after graduation. Prior research on teaming provides some ideas about how to design experience that promote effective teaming behavior.[2,3] We have experimented with multiple methods to support the process in first year engineering courses and anticipate these skills transferring to future team situations. However, we also recognize the need for teams to think with their domain knowledge as they engage in engineering activities. We are interested in the inquiry of how teams continue to use effective teaming process skills and learn to collaborate together to learn new content and to systematically make decisions related to activities like design, and troubleshooting.

Implementing a problem or project-based learning (pbl) approach to teaching requires putting more of the learning responsibility into the hands of the students. Some pbl approaches use team facilitators to help initiate teams into the process of investigating a proposed problem. (e.g. in engineering Newstetter[4]; in medicine, Hmelo[5]) The facilitator provides various levels of scaffolding in various forms. For example, he or she may introduce organizational tools such as whiteboards to manage idea generation and investigation of various options. The facilitator could initially assume the team manager types of responsibilities, and gradually hand over more of the responsibility to the students. The objectives are to help students learn to participate and lead these kinds of team design processes. An important point to note is that not all courses need to use the facilitation model. As students progress through the curriculum instructors can assume students can manage this process on their own. However, the instructor may be introducing new domain specific tools that teams can use to manage their design process and to monitor some level of the teams' productivity and cohesiveness. In an engineering undergraduate curriculum this kind of model is implemented by teaching teaming, design, problem solving and project management skills in the first year of engineering, then engaging students in design projects of various scales throughout the remainder of their undergraduate career. In designing these courses, instructors need mechanisms to monitor teams' progress and potentially provide feedback on their process and products. The ability to effectively engage in a problem based instruction will increase as students advance in their abilities to manage the process.

Problem and project based instruction in the early years of engineering education involve learning to manage inquiry and problem solve individually and as a team. As part of the experience instructors provide direction on the roles of team manager, recorder keeper, encourager, time keeper, alternative advocate and the strategies associated with performing these roles well. We also present potential pitfalls they may encounter during their process. For example, making them aware that team will progress through stages of forming, storming, norming, performing and adjourning and how the team's productivity depends on managing this progression. However, simply knowing that these definitions of teams and skills exist does not necessarily transfer to recognize how and when to use these ideas when teams' are engaged in the process. At our institution, first year students are given many opportunities to learn and practice the management of their team and project so their team is more productive. We anticipate the skills learned in the First Year Experience (FYE) will be mastered enough to transfer into future courses where the instructional focus is more on integrating knowledge into the design process and students can manage the team process and project.

Our instructional team is working to transform a conventional project based undergraduate (second year) aerospace design course into a multiplayer online virtual world using principles associated with serious educational games. This serious game provides a different learning environment for students to engage with content in the course and interact with their teammates using various tools to support their learning, collaboration and design process. Previously, we examined students' readiness to learn with technologies and engage in engineering design coursework via the means of serious educational games.[6] The next step was to develop a detailed description of how team members interact to perform various engineering tasks such as analyzing components of systems and making design decisions. This paper presents results from one of our instructional design pattern [7,8] (called quests in the virtual world) involving a team process of evaluating design alternatives given to them (as opposed to their generation of design alternatives). The immediate goal of this particular study was to identify the features of team's decision making process and tool use. Results of this study have implications on the development of the virtual world intended to facilitate teams' decision making process and overall design project processes.

Quest Types for Instruction

Several instructional design patterns, or quests in the virtual world, can target different instructional goals. Design patterns are a collection of learning activities sequenced in a way that produce predictable and repeatable learning objectives.[7,8] The different instructional goals can include delivery of content knowledge (familiarizing students with facts and vocabulary), developing conceptual understanding (students demonstration of replicating, application of principles to well defined problems) or to foster innovative ideas which involves synthesizing concepts, generate ideas and transform them into innovations. In the aerospace design course, students develop their conceptual understanding of the domain knowledge through lectures, and team based "quests" (i.e. learning exercises) that involve analyzing ambiguous problems, troubleshooting, analyzing performance and design decision making. One such learning quest is presented in this paper that deals with a rocket configuration exercise, where student teams work in a face-to-face environment to evaluate various rocket configuration and identify and explain why different solutions are best when considering cost, weight and drag.

Methodology

Case study approach[9] provides the best method to describe the interaction of team members and the critical events that occurred during their negotiation of the team's final decision and rationale. The following sections present details on the participants, procedures, initial analysis and discussion of relevant episodes from the case study.

Participants

Two teams (team A and team B) were recruited to work face-to-face on the rocket configuration quest. Each team consisted of 7 members. Team A consisted of 1 female and 6 male students and team B consisted of 2 female and 5 male students. The teams worked in separate conference rooms with seating arrangements as shown below in Figures 1 and 2. Labels S1 to S7 indicate students. These seating arrangements ensured students had a direct visual of each other and a shared work space between them. Informed consent was obtained from the students and the research team made it clear that the students' participation was completely voluntary. The session was video recorded for later analysis and field notes were taken during the session.

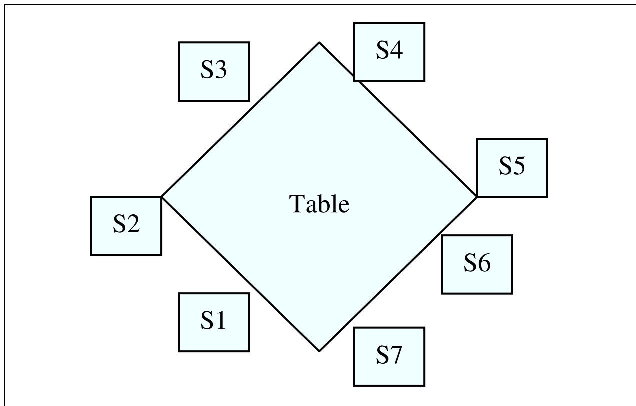

Figure 1. Team A seating arrangement

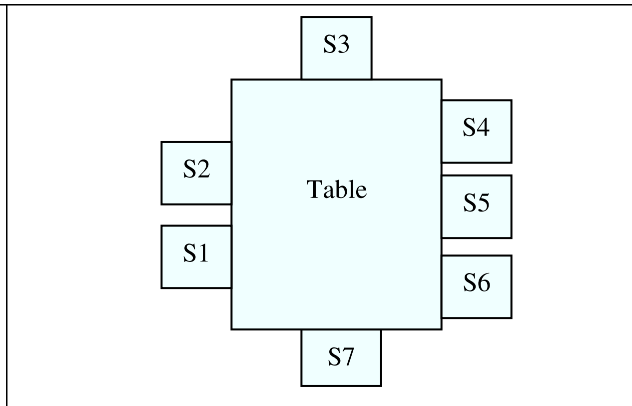

Figure 2. Team B seating arrangement

Procedures

The team quest presented to the students involved a rocket configuration exercise. This exercise (see appendix) consisted of multiple choice questions that target various design consideration students would need to make and their rationale for their selection. The first part of the quest provided students an opportunity to work individually on the quest. Next the team worked together to identify a consensus choice and rationale for each question. Once the teams completed their synthesis of solutions and rationale, they were given feedback on the correct multiple choice item. The students were then asked to score their individual and team responses and rework the rationale for any of their incorrect team responses.

Students were expected to self organize and work independently and with their team without any instructional guidance. The only input from the instructional team was a description of the activity sequence and providing the correct responses at the end of their team session. This session lasted for 1 instructional period equivalent to 50 minutes. Data was collected in the form of video recorded observation of the students and all written materials generated during the quest. The implementation sequence for the session consisted of the following steps:

Table 1. Steps of instructional sequence for the design pattern

1. Distribute question sheet and individual answer sheet
2. Individual working time – 12 minutes
3. Collect individual answer sheet
4. Distribute team answer sheet
5. Team working time – 12 minutes
6. Collect team answer sheet
7. Provide correct responses
8. Students self grading- compare individual average scores and team based average scores
9. Team reflection and reworking the incorrect responses
10. Collect all remaining materials and end the session

Analysis

In this section, we present a description and analysis of selected episodes from the recorded observational data of the two teams working on the rocket configuration quest. These episodes were selected as they relate to our research goals to determine the major events teams transitioned through to select a shared team answer. Our unit of analysis is at the team level. Team A spent a bulk of their time in negotiating a response to Q.1., and team B had extensive interaction negotiating a response to Q.6. These events became the focus of analysis for this study. We present these two respective episodes below.

Case 1: Team A

Team A started their discussion with each member sharing their thoughts and comparing individual selection of multiple choice item and rationale. When they shared the same answer, then recorder (and emergent team leader) listed each team member's main points as the collective rationale. The team was split mainly between two multiple choice answers: (a) and (b) for Q.1. Out of the 7 team members, student S4 was very vocal and presented several technical reasons (e.g. materials, sub-systems etc) for his choice for Q.1. This student (S4) provides several analogies to support his choice. For example: "in our CGT class, we had a design tradeoff- you increase one thing and it changes the whole thing- it's not just redesigning the system." After most of the team members (5) expressed their viewpoints, a long silence (pause) ensued and then several students indicate the need to decide on a final team answer. At this stage, again the students begin to negotiate which answer choice should be selected for Q.1. Student S1 highlighted their assumptions. At this time, the conversation goes back and forth between S1 and S4, while others listen. Eventually, S1 states: "so I don't think everyone is going to be on the same page on this one, but I am personally willing to compromise with what everyone thinks." S1 is also the team recorder and plays the role of timekeeper. In order to be on task, S1 asks for a vote on Q.1. The team spends approximately 12 minutes negotiating this response.

For team A, 4 out of 7 students had individually a correct response for Q.1., and as a team they identified an incorrect choice. When students were provided feedback (step 7 in Table 1) about the correct multiple choice response to Q.1., they were asked to rethink their original team rationale. At this point, one of the more vocal team member, student S4 exclaims "so basically everything that I assumed was wrong". This could be considered a learning moment for S4 as well as the team. They acknowledged that their original assumptions were not accurate and subsequently they had an opportunity to generate an explanation that would support the correct answer choice.

Case 2: Team B

Team B shared and then discussed each of their individually selected multiple choice questions and rationale for each questions. After approximately 10 minutes into the team discussion of responses, students focused on Q.6 since the team did not have a unanimous vote. Student S3 starts the discussion by making sounds and gesturing with paper objects to provide an explanation of where aerodynamic drag will be the highest. This is immediately followed by counterarguments by students S1 and S4 who present their own explanation of the phenomenon. Student S3 is quite fixed on his response choice and states his opinion to the team. Now, S5 jumps in the conversation with a sketch to try and explain the phenomenon. At this time, all team members gather around the sketch while addressing multiple concerns. Student S3 continues the conversation after a brief pause by asking: "What's another good example on it?" This is followed by a discussion of an example of a Parachute and its features. Other team members pitch in their thoughts by gesturing and utilizing sketches. When decision and consensus is not reached, S3 continues to further his argument with his own new sketch. S1 continues to provide counterarguments to support another response. At that time, S3 exclaims "I am sticking to my guns" The team continues to elicit the rationale, and finally decides to vote on the response as team recorder (S6) asks: "so we are all saying A?" In the end, student S3 backs off his choice and decides to support the response reached by consensus. As the team recorder (S6) notes the rationale for this choice, student S3 makes a last attempt to change the team response by providing another analogy. Eventually, the team recorder (S6) decides to put an asterisk next to the team response acknowledging that they had a valid argument for another answer choice as well. The team spends approximately 10 minutes on this question.

In team B, 4 out of 7 students individually selected the correct answer choice for Q.6, and their team response was also correct. When the feedback was provided for the correct responses, the team was asked to rethink their rationale only for their incorrect choices. As team B scored Q.6 correctly, they did not reflect back upon this question.

Discussion

Table 2 categorizes the various observations from the two cases. We find that students are able to present their arguments through various forms. Especially in engineering design problems, visual representations and diagrams play an important role. This use of sketches is demonstrated by team B while negotiating their responses. Other studies acknowledge that design language is greatly supported by the visual aspects of design.[10] Furthermore, both teams A and B use examples and analogies to support an argument and present counter evidence for a particular selection. Negotiation and compromise with team members is another aspect that is noticed in these episodes. Some vocal team members in both teams drove the conversation and some silent team members did not provide as much input to the team discussions. This is a common aspect observed in team environments. The team recorder in both teams also played the role of the timekeeper and tried to get the team's consensus on a particular response. It indicates that these dual roles allowed them to get closure on the final decision within their respective teams. Students are able to discuss technical aspects of a design based upon their prior knowledge. For the most part, students are able to self regulate and remain on task. The various ambiguous responses in the questionnaire and ability to provide a rationale for each selection allow students to explore multiple options and state their assumptions.

Final Remarks

This learning quest provided students an opportunity to self-regulate their understanding on the basis of negotiation and discussion with their peers, and develop a rationale for their solutions. After the feedback from the instructional team, the student teams had another opportunity to rework their incorrect responses and come to a shared understanding of the correct answer choice and rationale. This reflection piece was valuable to rectify any misconceptions. Closing the instructional loop with such formative feedback is essential in developing students' knowledge.

Often, team dynamics are complex interactions where members have to come to a consensus and negotiate in a give and take environment. Although research on decision making and negotiation has been done in diverse fields such social sciences, and management, very few accounts are specific to engineering design.[11] Our case study of the two teams highlights interactions of the team members while engaged in a decision making process. A glimpse into these team dynamics and details of executing such a learning quest are presented in this study. These insights will be valuable for instructors whose learning objectives target decision making by individuals and teams working on complex design challenges. Instructors can build upon the structure of this design pattern (Table 1) presented in this study and anticipate similar potential student learning outcomes.

The features of the engineering design decision making process also inform our design of a virtual world intended to facilitate teams' decision making process and overall design project processes. From this particular learning quest, we learned that students would need a sketching tool, a pointer, an ability to create artifacts to demonstrate a concept, an ability to gesture, access to study materials and a shared meeting location where they can negotiate and discuss their ideas. Finally, students required a note-taking tool to document their responses and rationale. If we were to implement this exercise in a 3D virtual world, then it would need to be designed to provide such affordances. Other types of instructional quests may require additional features in the virtual world. Our research team is continuing to investigate these issues in further studies.

Table 2. Engineering design decision making process in a face-to-face environment

Observations	Evidence Case 1: Team A	Evidence Case 2: Team B
Visual representations such as sketches are an important part of engineering design decision making		S5 jumps in the conversation with a sketch to try and explain the phenomenon. At this time, all team members gather around the sketch while addressing multiple concerns based upon the explanation and the sketch provided by S5. When decision and consensus is not reached, S3 continues to further his argument with his own new sketch.
Artifacts (eg. paper planes) aid in explanation of technical content (eg. drag)		Student S3 starts the discussion by making sounds and gesturing with paper objects to provide an explanation of where aerodynamic drag will be the highest.
Use of analogies and examples to support arguments and advance the decision making process	This student (S4) provides several analogies to support his choice. For example: "in our CGT class, we had a design tradeoff- you increase one thing and it changes the whole thing- it's not just redesigning the system."	Student S3 continues the conversation after a brief pause by asking: "What's another good example on it?" This is followed by a discussion of an example of a Parachute and its features.
Effect of dominant team members – some team members in both cases took control of most of the discussion	Out of the 7 team members, student S4 was very vocal and presented several technical reasons (e.g. materials, sub-systems etc) for his choice for Q.1.	At that time, S3 exclaims "I am sticking to my guns"
Team member's role in converging on a decision & building consensus - Instead of a designated team leader, the recorder played the multiple roles of time keeper, team manager and recorder.	Eventually, S1 states: "so I don't think everyone is going to be on the same page on this one, but I am personally willing to compromise with what everyone thinks." S1 is also the team recorder and plays the role of timekeeper. In order to be on task, S1 asks for a vote on Q.1.	The team continues to elicit the rationale, and finally decides to vote on the response as team recorder (S6) asks: "so we are all saying A?" In the end, student S3 backs off his choice and decides to support the response reached by consensus. Eventually, the team recorder (S6) decides to put an asterisk next to the team response acknowledging that they had a valid argument for another answer choice as well.
Negotiation and compromise	Eventually, S1 states: "so I don't think everyone is going to be on the same page on this one, but I am personally willing to compromise with what everyone thinks."	In the end, student S3 backs off his choice and decides to support the response reached by consensus. As the team recorder notes the rationale for this choice, student S3 makes a last attempt to change the team response by providing another analogy. Eventually, the team recorder (S6) decides to put an asterisk next to the team response acknowledging that they had a valid argument for another answer choice as well.
Access to prior knowledge in decision making	Technical aspects discussed by various team members-referring to class notes at times	

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Appendix: Team Quest - Rocket Configuration

Aers V launch vehicle, currently developed for human missions to moon, has two solid rocket boosters (SRB) strapped on the side of the bottom stage. If we were to modify this rocket for mission to Mars, your team has determined, the amount of propellant for SRB needs to be doubled.

1. Which option will likely be the cheapest from manufacturing point of view?
   a. Use four SRBs instead of two.
   b. Use larger SRBs, enlarged proportionally.
   c. Use longer SRBs, keeping the diameter the same.
   d. All options are the same for this particular problem.

2. Which option will likely be the most expensive from manufacturing point of view?
   a. Use four SRBs instead of two.
   b. Use larger SRBs, enlarged proportionally.
   c. Use longer SRBs, keeping the diameter the same.
   d. All options are the same for this particular problem.

3. Which option will likely be the lightest?
   a. Use four SRBs instead of two.
   b. Use larger SRBs, enlarged proportionally.
   c. Use longer SRBs, keeping the diameter the same.
   d. All options are the same for this particular problem.

4. Which option will likely be the heaviest?
   a. Use four SRBs instead of two.
   b. Use larger SRBs, enlarged proportionally.
   c. Use longer SRBs, keeping the diameter the same.
   d. All options are the same for this particular problem.

5. Which option will likely have the lowest aerodynamic drag?
   a. Use four SRBs instead of two.
   b. Use larger SRBs, enlarged proportionally.
   c. Use longer SRBs, keeping the diameter the same.
   d. All options are the same for this particular problem.

6. Which option will likely have the highest aerodynamic drag?
   a. Use four SRBs instead of two.
   b. Use larger SRBs, enlarged proportionally.
   c. Use longer SRBs, keeping the diameter the same.
   d. All options are the same for this particular problem.