Final Consulting Report

Academic Teams: Engineering Capstone and Design Courses

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1.0 Team Overview

Our team for this project was comprised of four members; Andrea Francioni Rooney, Henry Peck, Gaurav Begur, and Ning Guan. Andrea is a staff member and academic advisor to Carnegie Mellon's Civil and Environmental Engineering program, Henry is an integrated Master's/Bachelor's student in Biomedical and Mechanical Engineering (2019), Gaurav is a Materials Science and Engineering student with an additional major in Biomedical Engineering (2018), and Ning is an Electrical and Computer Engineering student (2018).

This project serves as the comprehensive final for the Innovation in Teamwork course, taught by Dr. Linda Flower. A complete list of contributors can be found in the acknowledgements section.

2.0 Problem Background

Students at Carnegie Mellon are often asked to work on team-based projects in their courses. Team projects are thought to provide hands-on experience, chances to apply knowledge, and opportunities to exercise human relations principles.

In the engineering industry, there is a growing focus on teamwork. This emphasis is being mimicked by the university in an attempt to better prepare students for the workforce. Through engineering capstone and design courses, students are given the chance to work in cross-functional teams and bring concepts to life.

Because the focal point of these courses is still the technical training, the team aspect has not been thoroughly investigated. As such, we have seen a disconnect between what students and faculty expected versus what is actually happening in teams.

By interviewing both students and faculty to learn about issues and successes they have experienced, our project team will investigate what lead to the practices within teams. We hope to answer the following: why do people do what they do, and what common issues can we glean across the board? We hope to reveal contradictions between expectations and recognize opportunities for innovation in teamwork across all academic years for courses in the College of Engineering and beyond.

3.0 Procedure

To conduct our study, we first identified the population that we were interested in observing. Seeing that our project roots were in a course on teamwork and innovation, we decided to investigate students who are or were registered in advanced engineering design or project-based courses which require student-team participation. We expanded our scope to include not just the student teams registered in these courses, but also the professors and teaching faculty affiliated with them, as their support, vision, and insight is extremely valuable in understanding the landscape of the courses. We differentiated our study by extracting data from a variety of interdisciplinary and single-disciplinary capstone courses, bringing in cases from Civil and Environmental Engineering, Materials Science and Engineering, Electrical and Computer Engineering, Biomedical Engineering, Human-Computer Interaction, and Entertainment Technology.

Each member of our project team conducted a series of critical incident interviews, where we asked either a student or a professor to recall a confrontational situation which they encountered during their respective courses. Employing the problem-digesting techniques we learned in this course, we extracted objective details about each individual's situation.

Our student interviewees in this project are seniors or juniors at Carnegie Mellon University, all of whom have extensive teamwork experiences, both positive and negative. Most of them have intuitive knowledges of what works or not in student teams and how to make teams work. Our goal is to help them turn their tacit knowledge, the highly subjective insights and intuitions that are difficult to capture and share, into explicit strategies so that we can communicate to other people.

To tap the tacit knowledge, our team followed the steps proposed by Ikujiro Nonaka in his article "The Knowledge-Creating Company" on page 166. We first learned the tacit secrets of student teams by interviewing both students and professors at Carnegie Mellon University. Then, we translated their "secrets" into explicit knowledge by doing critical incident analysis on interview transcripts. Lastly, we standardized these pieces of knowledge by relating them to the theories and research discussed in our course.

Although our sample size is small, we built a corpus of incidents comprehensive enough to illuminate common issues across the departments, and further develop our understanding of teamwork in upper-division engineering courses.

4.0   Key Issues and Analysis

As we examined the teamwork practices among the engineering project courses, we found three key issues: 1) team documents like a team charter were usually required but not always put into use by the team; 2) teams were created so that various skill sets were represented, but the team members often worked alone as their skills were needed; 3) teams whose members knew each other well sometimes had difficulty in keeping personal relationships from influencing teamwork. To better represent these issues in practice, we prepared a series of skits to replicate the scenario. These skits reflect real situations that came from our critical incident interviews with students and faculty. Subsequently, we analyzed the activity through the lens of theories and research discussed in our course.

4.1   Tools as a Key Issue

Most teams that we studied had a requirement of a team charter, team resume and/or schedule. However, we found that the teams often create the requirement for the assignment, but do not incorporate the documents into their team activities.

Instructors expect that the practice of creating team documents like a charter, resume or schedule will help the team manage their time and activities. In practice, we found that students ignore the documents once they have fulfilled the requirement, unless incentives are put into place to make the continued use of the documents a part of the team's routine. **The skit to demonstrate this issue can be found in Appendix A on page A-1.**

As outlined in Joanna Wolfe's book *Teamwriting: A Guide to Working in Groups*, many teams begin their workflow with a formal document outlining future responsibilities. While this practice provides a guide for the groups, the incentive for follow through on the documents is not always present in the course. Without this additional incentive to refer to the team charter or revise the schedule, teams tend ignore the documents after they are created. Sometimes the creation of the documents is not always taken seriously, with penalties such as "buy the team lunch" or "take the team to happy hour" listed for missing a meeting or a deadline.

Teams that overlook useful tools like team charters and project schedules tend to run into organizational problems, such as missing deadlines or confusion of responsibilities. In "Developmental Studies of Work as a Testbench of Activity Theory", Yrjö Engeström identified four essential components in teamwork: roles, rules, tools, and contradictions. Team charters are important mediation tools which also define another two components: roles and rules. Team charters can be helpful in reducing contradictions, if all team members understand each other's roles and rules.

Team charters and project schedules can also be used to facilitate shared mental states. "In Planning, Shared Mental Models, and Coordinated Performance", Reneé J. Stout argues that a shared mental model (SMM) among team members is essential for making successful decisions. There are cases when team members are not on the same page regarding what they want to achieve in the end or where they are in the process. This is problematic because team members rely on each other to provide information in order to move on with their project. Stout's study shows that "members of teams that engaged in high-quality planning were able to form a greater SMM of each team member's informational requirements, to pass information to each other in advance of explicit requests for this information" (68). With a shared mental model, team members are more ready to foresee problems, and thus to provide information in advance. As a result, better SMM results in higher efficiency and fewer errors. To develop SMM, teams have to leverage tools such as team charters and project schedules to help them plan ahead. Without understanding of each other's roles, teams are not able to function together to predict and solve problems.

With established team charters, project schedules and shared mental states, teams are ready to tackle the core issues of the project which utilize their individual skill sets. So, what can people do to take advantage of diverse skill sets in the team to create a rewarding teamwork experience for everyone and improve the quality of the final result?

4.2   Skills Sets as a Key Issue

Teams are often created by instructors with the intention of representing a wide range of skill sets among the team members. For example, in the Civil and Environmental Engineering capstone course, teams often contain at least one member who has structural engineering experience, at least one who has environmental engineering experience, and at least one who has computer modeling experience.

Instructors expect that arranging the teams with various skill sets represented means that all aspects of the project will be covered comfortably. Students expect that they will likely be asked to work only in their skill set, although they may desire the chance to learn a new skill from a classmate. In practice, we found that while the skills are present to handle most project needs, the bulk of the workload shifts from team member to team member as their skills are called into play, creating an imbalance and the lack of opportunity to learn from each other. **The skit to demonstrate this issue can be found in Appendix A on page A-2.**

In the essay "Learning to Navigate", Edwin Hutchins asserts the notion of cross-training, in which someone with a specific strength leads an activity with the intention of others learning in real-time. This contradicts the notion of working in silos, which is what tends to happen in teams set up this way. With cross-training, all team members will obtain

exposures to all components in the teamwork. Hutchins also argues that developing overlapped skills also reduces errors and improves teamwork efficiency, especially in time-constrained situations. In "Learning by Expanding," Engeström asserts the concept of expansive learning as a phenomena which occurs when individuals involved in activity systems transform the rules and traditions to embrace broader possibilities. By not embracing the cross-training model asserted by Hutchins, the teams of these projects courses miss an opportunity for expansive learning. With this missed opportunity, students gain less academic and personal fulfillment from their project experiences.

However, the tricky part of having diversity in the team is the problem of potential representational gaps. In "Representational Gaps, Information Processing, and Conflict in Functionally Diverse Teams", Matthew A. Cronin and Laurie R. Weingart talk about how "diversity increases the likelihood that individual team members will perceive the team's task differently, leading to gaps between teammates' interpretations of that is needed for the team to be successful" (761). For example, in the case of Civil and Environmental Engineering capstone course, if the professor asks the project to be "technical", the structural person might interpret it as technical "structural wise", while the computer modeling person might interpret it as technical "model wise". If team members do not talk out their expectations, they are likely to run into conflicts later when they do not think others are pulling their weight. Furthermore, Cronin and Weingart suggest that "Coordination errors can occur when team members have misunderstandings because they hold different GAEO (Goal hierarchy, Assumptions, Elements, and Operators). Different interpretations of information can cause people to make moves that work against others' actions" (768). On the one hand, diverse skill sets are highly valued in teams, because homogeneousness almost always sacrifices the quality and the scope of the solution. On the other hand, diverse skills, if not leveraged properly, can cause serious problems in teamwork. Cronin and Weingart propose the solution to close representational gaps by calling for "expanding people's representations so that they include the capabilities and concerns of others" (770). To achieve that, team members should "teach enough functional knowledge to others with different backgrounds to allow for shared understanding" (Cronin and Weingart, 770). Cronin and Weingart not only speak to Stout by recognizing the importance of shared mental model, but also speak to Hutchins who argues that cross-training in teams produces better results.

In all, diverse skill sets in teams are a virtue. However, people need to put in efforts to take full advantage of them. Teams should be wary of representational gaps, a side effect of diversity. Representational gaps could be closed by cross-training, overlap of skills, and shared mental model.

4.3   Personal Relationships as a Key Issue

Students often want the opportunity to choose their own teams, but sometimes when friends work together, professional behavior is difficult to maintain. In many cases, instructors assign teams. However, in smaller departments, the situation of students working with friends is difficult to avoid. Instructors expect students to respect each other's contributions and time while working in teams. Students expect that working with friends will be easier and more productive than working with acquaintances. In practice, we found that when working with friends, students sometimes have difficulty with productivity and professional behavior. Personal feelings seem to get in the way of good teamwork practices. **The skit to demonstrate this issue can be found in Appendix A on page A-3.**

On a positive note, teams where pre-standing relationships exist tended to open their mind for differences and expressed willingness to explore different approaches before reaching a conclusion; a practice asserted by Dr. Linda Flower in her paper "Difference-Driven Inquiry", where she argues that "Consensus often comes with costs, because minority positions are often pressured into silence or simply co-opted" (319). Flower stresses the importance of giving voice to minority discourses, where differences are, in order to achieve a broadened understanding of the problem and propose effective solutions. If a team always ignores different voices, they fall into the trap of following the established working process. But to be innovative, team members first need to recognize the fact that people have different beliefs and assumptions, and second, they need to work on rhetorical strategies to draw out such differences over conversations, by asking more open-ended questions.

However, team members who are good friends with each other were hesitant to be too emphatic or strongly supportive of their own idea in an attempt to avoid conflict. The team members did not want to make waves by pushing their own agenda, which ended up slowing the progress of the whole team.

5.0   Rivals

Through critical incident interviews with students in interdisciplinary project courses, we discovered practices and notions which differed from our observations in pure College of Engineering courses. In doing so, we extrapolated the following rival hypotheses which provide new context for critiquing our prior analysis.

5.1　Rotation of Roles and Leaders' Roundtable

In one interdisciplinary course between students in Electrical and Computer Engineering, Computer Science, and Human-Computer Interaction, team members were required to rotate through different roles such as leader, note taker, and report compiler. Moreover, the leaders from each sub-team in the course would meet weekly for a roundtable with the professors to provide progress updates and work through issues that may be present. **The skit to demonstrate this issue can be found in Appendix A on page A-5.**

By requiring students to occupy defined positions, there were clear roles for each member of the team. The frequent rotation of roles ensured that no one person was dominating the group, or made to feel "in charge." The leaders' roundtable provided a much needed forum for students to come together and share issues, while simultaneously receiving guidance from the professors and their peers.

5.2　Friendship as a Positive Factor

After taking an interdisciplinary virtual reality class, one student shared their experience of bouncing back from adversity in a group project. After the professor of the course rejected the team's concept and prototype for a final project almost halfway through the allotted work time, it was the prior relationship these students had which allowed them to rebound effectively. **The skit to demonstrate this issue can be found in Appendix A on page A-7.**

Although prior relationships can create ineffective team dynamics as seen in our prior example, this team leaned on their friendship when faced with a tough situation.

6.0 Insights from Discussion

We were pleased to receive several thought-provoking questions at our project presentation. Based on the frequency that the lack of use of team documentation was mentioned in our critical incident interviews, we expected that issue would be of focused interest. However, the faculty members in the audience seemed not surprised that teams often failed to use their team documentation as part of their operations. Instead, the conflict between the desire to learn new skills and the lack of time to allow for student cross-training in tight project schedules seemed to capture the audience's attention.

Carnegie Mellon alumni often cite their ability to learn how to learn as one of the most important skills they gained as students. That skill would be even more enhanced by allowing time for cross-training within group projects. Students will not only increase their confidence in how to learn, but also in how to share that knowledge with others.

The need for conflict resolution training in student groups was also noted by the faculty in the audience. Directed instruction in conflict resolution will not only help student groups work through challenges, but will also carry over as useful tools for professional teams as students transition to their careers.

7.0 Avenues of Further Observation

Our study provides high-level insight into various team dynamics that either created, prevented, or encouraged positive teamwork outcomes. However the study is somewhat limited in scope, as observers interviewed students & teaching faculty affiliated with upper division classes largely within the College of Engineering majors. To further characterize teamwork at Carnegie Mellon, the study must be expanded to include other schools (Tepper, Dietrich, etc.), consider teamwork at different ages (not only upperclassmen), and account for variability in course loads (academic involvements, additional majors/minors, specialty major tracks).

Furthermore, another avenue of further observation worth exploring is teamwork in the digital age. This seeks to understand the role of communication technology in student teams. Looking into industry, companies such as Slack demonstrate the necessity of collaborating in digital teams when working on grand-scale projects and programs. It would make sense that the tech-savvy students of Carnegie Mellon also adopt formal team communication channels, such as a team GroupMe or Slack page. Technology certainly plays a huge role in students' social communication circles, so its effect in academic settings should be observed. Details surrounding project documentation protocols, file-sharing services, and collaborative tools that students use can provide further insight into the anomalies of teamwork at Carnegie Mellon.

8.0 Acknowledgments

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Appendix A – Scripts of Presentation Skits

Skit 1 "Team Squabble"

Skit 1 illustrates the concept of tools as a key issue, described in Section 4.1.

(Jessica and Zach are seated in a conference room, talking and reviewing notes. Evan rushes in.)

Jessica: Evan you're late again

Evan: Sorry, I had another meeting, I'll buy you all lunch this week

Zach: That's not the point, you're 30 minutes late! We're never going to get this done if we don't show up on time

Evan: Hey you're the one who didn't submit the report draft on time last week, so don't get mad at me for being late to one meeting. Besides, we've all been late before, Jessica was late two days ago

Zach: I had two other deadlines that same day, don't throw that in my face now!   And besides, Jessica is the one who is supposed to be in charge of that kind of stuff

Jessica: The bus was running late on Tuesday, there was nothing that I could do! And since when am I supposed to be in charge, Evan was the one that did research with signal processing before

Evan: Whatever, sorry I was late, let's just get this started

(End of scene)

Skit 2 "Missed Opportunities"

Skit 2 illustrates the concept of skill sets as a key issue, described in Section 4.2.

(Sally, Greg and Dave are seated at a group table in a computing cluster. They each have their laptops open in front of them.)

Sally: Okay, now that we have our basic concept selected, we need to do the structural calculations and create the computer models

Greg: I can try doing the computer models with Dave! I haven't done it before but I'm trying to learn before I graduate

Sally: We need you to do the structural calculations, you're the only one who has that specialty. Dave has done computer modelling before so he can handle that part by himself

Dave: I agree, if you do the structural calculations and I do the modelling things will go faster and we can stay on schedule

Greg: So who is going to do the environmental analysis?

Sally: I can do that, I worked on stuff like that at an internship last summer

Dave: Great, so once Greg finishes the structural calculations, i can do the modelling and Sally will do the analysis.

(End of scene)

Skit 3 "Killing the Project with Kindness"

Skit 3 illustrates the concept of personal relationships as a key issue, described in Section 4.3.

(Julie, Adam and James are seated at a table in a department student lounge. They are reviewing sketches of a bridge project.)

Julie: I think the best way to affix the bridge to the post is to use the method from the textbook which we covered in class.

Adam: Are you sure? I mean we can try, but I don't know if it's going to work out that well

James: Yeah I think that there are probably some other ways we can do that…I saw this one method online which seemed to work for an industry project which was similar. Do you guys think we should look at that?

Adam: I have a friend who took the class a few years ago and their method worked well, we might want to use that one

Julie: I'm okay trying them all I guess but I'm pretty confident that the method I have will work out well

James: So we want to try out all the methods and see what happens?

Adam: We could do that. It will take a lot of time though

Julie: Yeah, that's true. We don't have a lot of time to spare.

James: Okay, so we'll run through the possibilities when we meet tomorrow. I have to get to class. See you tomorrow.

Julie: See you.

(James exits the lounge.)

Adam: Julie, I think that your method is probably the best way to go.

Julie: Then why didn't you say so?

Adam: You know James. He likes to be absolutely sure. Remember the contingency plans that he put together for our road trip last summer?

Julie: Oh, right. Plans A through D. We never needed more than Plan A though. He just wasted a lot of time putting together "what if" scenarios. We don't have that much time for this project. If you and I are both in favor of my plan, we should just go for it.

Adam: But James will be anxious for the rest of the project. Those "what ifs" really get into his head. We should just try out all of the designs for his piece of mind. Otherwise, we'll lose time later with constantly trying to convince him that the choice was the right one.

Julie: I suppose it's better to use some time now then.

(End of scene)

Skit 4 "Team Leaders United"

Skit 4 illustrates the rival idea of rotation of roles and use of a leaders' roundtable, described in Section 5.1.

(A professor and three students are seated at a conference room table. They each have notes or a laptop in front of them.)

Professor: Okay, team leaders, let's get started on progress reports. What did you hear from the parent focus groups for the Children's School information system redesign?

Leanne: Well, professor, the parents that our team spoke with suggested a messaging function on the parent portal, so they could leave daily notes for teachers. Right now, they relay information in person as they drop off the kids at the school, but sometimes that can hold up traffic, and the teachers have to try to remember what was said about several kids at a time.

Thomas: We heard something similar, but the parents wanted in an app version, so they can send last minute notes if needed.

Professor: That's a good suggestion. Have any other teams looked at developing a mobile version?

Alex: We discussed it, but we were concerned about how adding that request would impact our team schedule. We have a four day cushion built in, but I'm not sure that'll be enough time to do a mobile version, too.

Professor: Could we do a poll of the parents and teachers to see if they would rather have desktop or mobile access?

Leanne: I think we can get that done. Jess is acting as our client liaison this week, and she's scheduled to move into the team leader role next week. I'll ask her to create a poll and she can report back at next week's team leader meeting. Thomas, Alex, could the client liaisons from your teams work with Jess to get the poll done quickly?

Thomas and Alex: Sure/Yes.

Professor: Good. Now did your team encounter any obstacles last week?

Alex: We had one team member who had to go out of town for an interview on short notice. We adjusted the team task schedule. He swapped the analysis he was scheduled to do last week with Megan, who was originally scheduled to do product development later in the project.

Professor: Well, I hope he got the job. Okay, that's it for this week's team leader meeting. It's a role rotation week, so please let your incoming team leaders know that we'll have a leaders' meeting in the same time and place next week. Thanks, everyone.

(End of scene)

Skit 5 "Friends First"

Skit 5 illustrates the rival idea of friendship as a positive factor, described in Section 5.2.

(Alexa, Ricardo and Jack are standing in a hallway of an academic building.)

Alexa: I'm so done with Professor Jones! How are we supposed to start this project over again?

Ricardo: It's ridiculous. There's a week left until the showcase and he wants us to change the whole thing.

Jack: Yeah it's gonna be really hard, but I think we'll be alright. We're just gonna have to pull a few late nights and grind it out.

Alexa: (sighing) It's like 251 all over again.

Ricardo: Oh my God! I almost forgot about that final. Remember how long we spent studying?

Alexa: Like 60 hours minimum, but we ended up doing pretty well

Jack: Should we plan on meeting up later tonight?

Ricardo: Yeah, let's all clear our schedules. I'll order some pizza and we can grab a room in Hunt.

Alexa: Okay. Let's all try and come with some ideas ready to talk about.

Jack: Awesome, see you guys then!

(End of scene)