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Communication Among Undergraduate Engineers on a Self-Directed Team During a Product Decision Meeting

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Abstract

Communication is critical to effective collaboration and decision making in both student and professional engineering teams. While teamwork is often assigned at the undergraduate level, the increasing emphasis on preparing students for the workplace has spawned interest in self-directed student teams that possess a higher degree of autonomy over decision making. This naturalistic study analyzed communication within two self-directed design teams in an undergraduate mechanical engineering capstone course at the Massachusetts Institute of Technology (MIT), in which 8 student-led teams initiated and developed new product prototypes over the semester. Insights presented here, from the first part of the full study, focused on a pivotal, relatively high-stress meeting, in which all 24 members of each team collectively discussed four product options and decided on one product to prototype. The audio recording and transcript of the meetings was used to compare the duration of time devoted to the students' presentations of the four different product ideas, as well as the free-form question-and-answer sessions that followed each presentation. The quantity and distribution of verbal participation from individuals during each Q&A discussion was also calculated. Although limited in scope, results of this first study suggest a correlation between the duration of Q&A sessions, distribution of communication responsibility among individual team members, and final product selection. Furthermore, a total of 23 out of 24 students (96%) on Team A and 20 out of 24 students (83%) on Team B asked and/or answered questions during the discussions throughout the meeting, suggesting that the stress and emotion of the high-stakes meeting may have reduced social loafing and contributed overall to students' verbal participation.

I. Introduction

In the workplace and the academy, professional engineers, researchers, and students typically function in teams. Even if individual team members have diverse technical backgrounds and expertise, the effectiveness of their work together depends on more than engineering 'chops'. In order to negotiate, plan, motivate, and integrate tasks at the team and even department level, engineers must practice and become skilled at interpersonal tasks like "communication, collaboration, networking, feedback provision and reception, teamwork, lifelong learning, and cultural understanding"[1]. As a collective rather than individual endeavor, the experience of working on a team may encourage an individual to perform at a high or low rate in terms of productivity, as well as communication quality and quantity.

Interdependence is the foundation of teamwork, as "teams produce outcomes for which members have collective responsibility and reap some form of collective reward"[2]. Rather than simply being a group of individuals completing a shared task, a team involves a collection of interdependent skills, knowledge, resources, and priorities directed toward a physically or cognitively demanding task that no individual could accomplish alone[3]. The dependence on others presents opportunities and challenges concerning integration, efficiency, and creativity[2].

Communication is especially critical to effective collaboration in an engineering team, not only in e-mail messages, memoranda, and internal reports, but also in verbal communication that happens in meetings that are the ‘lifeblood’ of contemporary professional life[4]. Although employees and their managers in the workplace attend on average more than three meetings per week, “the quality of these meetings is evaluated as poor in 41.9% of the cases[5,6]. Furthermore, dissatisfaction with the meeting procedure and results affects employees’ attitudes and leads to a negative and pessimistic perspective on meetings”[6,7]. The failure of teams to work together affects more than individual attitudes and satisfaction; it affects the outcome[1,8,9,10]. Software specialists DeMarco and Lister argue that project results are due less to technical issues and more to ones related to teamwork[11 ctd. in 12]:

> If the project goes down the tubes it will be non-technical, human interaction problems that do it in. The team will fail to bind, or the developers will fail to gain rapport with users, or people with fight interminably over meaningless methodological issues.

Team performance depends on the ability of its individuals to perform *with others* many cognitively demanding tasks: teams think, plan, design, decide, perceive, and even remember[3]. Central to the performance of these tasks at the team level is communication.

As a result of industry pressure, internal surveys and reviews, and even alumni feedback, educational institutions have been encouraging instructors and faculty to provide “authentic team experiences” that prepare undergraduates for a workplace that demands strong communication and collaboration skills[12]. While many educators have long used group projects and teamwork to provide peer learning experiences, more recently scholars and practitioners have been calling for a more deliberate shift in university curricula that will equip graduates to work better in teams in their professions[1].

Because of the emphasis on teams as the basic organizational structure in business and industry, and because “the group interaction process is viewed as a central component for predicting team outcomes”[5], universities and accreditation boards have recognized that an explicit focus on the development of team communication is necessary in a curriculum that prepares undergraduates for the professions. For example, at our institution, the Massachusetts Institute of Technology (MIT), a 2013 strategic report on the future of education asserted that the “ability to work and communicate effectively in a team is a critical 21st century skill,” and it made several broad, curriculum-based recommendations for developing those skills in students[13].

In this study, we are particularly interested in communication skills that enable decisions among teams. Yang has observed that

> While decision-making style appears to play an important role in team effectiveness, there is little research on its value specifically for design teams. Research on decision-making in design has focused on strategies for modeling design choices themselves, but less attention has been paid to the social aspects of how decisions are made during design[14].

Our roles as communication lecturers at MIT who are embedded in engineering and science courses to teach written and oral communication position us to advise and observe the social aspects of team decision making. For us, this is a particularly rich opportunity in the senior capstone course in the Department of Mechanical Engineering, 2.009: Product Engineering Processes, in which eight self-directed work teams (SDWTs), each composed of 20+ students, invent, model, test, and develop an alpha prototype for a new product. As communication mentors assigned to student teams each fall semester, we have seen student team members draw on course materials, the guidance of course faculty and lab instructors, and prior experiences in activities, sports, internships, and other classes as they conduct formal and informal meetings to explore design options, divide tasks, and make decisions.

Students at MIT are highly motivated, and the teams are typically effective at leading themselves through a design process that is taught and described in course lectures and materials. However, because there is a great degree of freedom in teams customizing details of the design process, it is not always transparent as to what specific communication strategies and choices enable teams to make progress as well as decisions. Our goal is to observe, capture, and analyze communication behaviors and study the discourse (or type of language) that aims to inform, persuade, or motivate an audience in a specific scenario/context. This study is informed by Herrington's analysis of written communication in chemical engineering design classes. Her study showed that writing assignments linked to a professional context (e.g. real problems experienced by a company) gave students an opportunity to learn through practice both a particular line of reasoning and social role appropriate to a community[15]. Furthermore, although our methodology is not conversation analysis (CA) *per se*, we are influenced by the work of Oak, Matthews and Heinemann, and others in the design research community who link conversation and face-to-face talk as a form of practice, with language, that people use to design things with each other[16,17].

In our full research study, we seek to observe and understand the specific role of face-to-face, verbal communication for two separate product design teams. We are focusing in part on the issues of proposals and consensus in decision making; we are also interested in how students approach communication as an essential team task. This naturalistic study qualitatively and quantitatively examines the respective team members' participation and rhetorical choices during two pivotal team decision-making events:

1. a three-hour lab meeting in which all 24 team members, who had previously been working on different products in sub-teams, collectively decide on one product among four ideas to iterate and build; and
2. a technical decision making meeting, a few weeks later, in which students choose the final design direction for an alpha prototype.

As communication instructors embedded in these teams, we have audio-recorded the meetings in order to observe, analyze, and characterize students' spoken communication. We have also interviewed a subset of students regarding their own and their peers' communication choices during the team meetings. We are conducting verbal data analysis on portions of the meeting transcripts.

This paper presents the first study that is part of the larger research project. Here, we report on two teams' product decision meetings. We analyze the amount of time devoted to the discussion of each of the four ideas, and the quantity and distribution of verbal participation from individual members.

II. Background

A. Self-Directed Work Teams

Researchers analyze and evaluate team performance based on a variety of characteristics, such as member demographics, the physical proximity of members, the organizational context within which the team exists, the pace and quality of decision making, outcomes, and hierarchical structure. A team with a horizontal hierarchy is referred to as "self-managing or self-regulating," in which "a manager or leader determines the overall purpose or goal of the team, but the team is at liberty to manage the methods by which to achieve that goal"[2]. The degree of freedom within self-directed work teams (SDWTs) affords each member greater control over his/her individual effort, productivity, and communication, which can positively or negatively impact team performance. Self-directed teams are increasingly present in the professional world, as "researchers have predicted that 75% of the top 1,000 U.S. firms will soon use some type of SDWT"[18,19].

Intentionally created self-directed work teams are rare in the academic setting, where teachers understandably seek to maintain greater control over students and processes to ensure learning objectives are met and enhance classroom participation. Within this culture, students certainly gain teamwork experience, as well as partake in self-directed team moments or events, though likely without knowledge or guidance on how to manage themselves successfully. University students accustomed to a high degree of faculty instruction and oversight likely have little or no prior experience in self-directed work teams.

In turn, students must quickly adapt to the new SDWT situation, as they suddenly find themselves in a familiar context – the university classroom or laboratory – but with an unfamiliar level of control over their decision-making, operational, creative, and communication processes. Douglas et al. describe how the formation of a self-directed work team "alters the structure of relationships by redefining the traditional roles of both managers and employees"[19]. Accordingly, faculty must adjust to the situation as well, relinquishing certain powers for the sake of student empowerment.

In terms of team communication, members in a SDWT undergo an experience of rhetorical discovery, a generative process of determining how to communicate effectively within or in front of an unfamiliar audience in a new context and genre. A member may seek to figure out how she herself should communicate and perform according to the values and expectations of the new situation, in part by observing the behavior of other members, and observing how members respond, verbally and nonverbally, to her own performance and contributions[20]. The students' roles also change from passive recipients to active creators of information and decisions. Their elevated status as decision makers enable them to impact the direction and outcome of the team, a role previously held by a manager or teacher.

In addition to the unfamiliar structure, the size of an SDWT may also be unprecedented for team members. The teams analyzed in this study comprise 24 students, respectively, well above the average range of 5-15 members in professional SDWTs [2,19], much larger than students (and many professionals) have ever experienced. Although large-sized teams have not been associated conclusively with negative work outcomes[2], research has shown that larger teams tend to exhibit a greater level of negative communication trends, such as decreased participation by certain members. In a 1963 review of 31 published studies focused on face-to-face teams of 2-20 members, Thomas and Fink identified the trend in which "the average number of participations per member decreased as size increased"[21]. An increase in team size has also been shown to correlate with more "frivolity of conversation" in meetings, and a greater amount of social loafing (Figure 1), the phenomenon in which "people in groups often do not work as hard as they do when alone"[2].

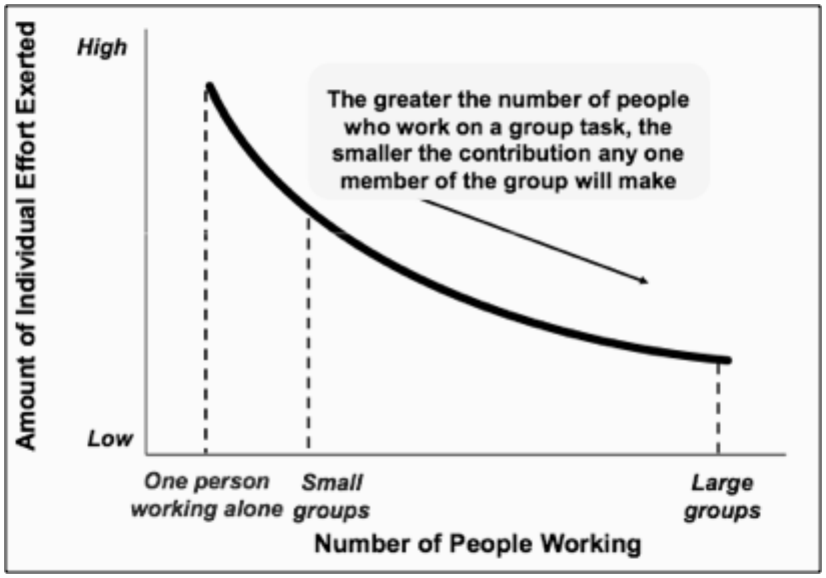

Figure 1. The Social Loafing Effect[22 ctd. in 2]

B. Communication as a Task

Through the lens of communication, a "communication loafer" could be an individual who excels in laboratory work, but refrains from contributing verbally in lab meetings. For example, in the student engineering teams studied here there exist high performers—individual members who go above and beyond when doing "engineering work," such as fabrication, research, and testing—but may assume the role of a "social loafer" or "free rider" with regard to the task of communicating during lab meetings. During the first team meeting of the term in the class studied here, Product Engineering Processes, students verbally identify members with specific expertise in key areas, such as fabrication, sewing, slide illustration, computer-aided design (CAD), and so-called back-of-the-envelope calculations. The process of identifying specialists on the team continues throughout the term, as students gain new opportunities to develop and demonstrate their skills. As the term progresses, teams also assign communication expertise to certain team members who have participated in earlier formal presentations in front of the entire class. Accordingly, team members might also implicitly designate communication expertise to individuals who often speak up and lead discussions during lab meetings. Kerr and Tindale describe a team's nonverbal designation of abilities and sources of knowledge to individual members as "the creation of a 'transactive memory,' a mutual awareness of 'who knows what,'" which can shape team decision making and team member participation during lab meetings[9].

In addition to relying on others perceived to be strong communicators, some team members may experience anxiety about communicating ideas and performing new tasks in front of the group. Drawing on research on the social and biological effects of interpersonal communication, Thompson writes

> Whatever we might be doing, we do it with more ‘gusto’ when in the presence of other people, especially our team. However, there is a catch: The presence of other people enhances performance for well-learned behaviors or behaviors that are almost second nature… but hinders our performance on novel tasks[2].

An individual who typically works alone or with a small group of familiar colleagues or classmates may become anxious and less confident when communicating to a new, much larger group of people. Another individual may lose confidence if the team’s discussion is outside of his precise area of expertise, as often occurs in classrooms (students are not yet experts), or if the communication task at hand involves new and unplanned intellectual territory, such as ideation or brainstorming. In these examples, the low- or non-participating individual may become a “free rider” not because of a lack of interest or desire to contribute, but rather due to “a reduced sense of self-efficacy” and confidence[2]. Pentland posits less global, more interpersonal reasons why a team member may appear unengaged:

> Are they trying to communicate and being ignored or cut off? Do they cut others off and not listen, thereby discouraging colleagues from seeking their opinions? Do they communicate with only one other team member? Do they face other people in meetings or tend to hide from the group physically? Do they speak loudly enough?[8]

Research has shown that emotion and stress impact individual and team communication during the decision-making process; however, results regarding the nature of the impact on communication are mixed. For example, De Grada et al. and Pierro et al. both found that groups under stress display “centralization of power/influence in a few influential group members (e.g., leaders)[23 and 24 ctd. in 9], manifest by greater conversational and power asymmetry in the group and communication patterns centralized on the more powerful members”.[6] However, Karau and Kelly found that “sometimes increases in stress (from low to moderate levels) can actually enhance aspects of group performance”[25 ctd. in 9].

The two teams in Product Engineering Processes, which are studied here, entered their respective product decision meetings with a relatively high degree of stress in knowing that one final product decision must be made. The meetings marked the end of the four sub-teams pursuing different products, and the beginning of team unification around a single product concept. The element of stress surrounding this important decision, which would undoubtedly disappoint some and please others, was a key factor for our study. Lehmann-Willenbrock et al. write that “action-planning is an emotional time for problem-solving groups. It is difficult and often contentious and is especially hard when consensus is expected”[10]. Examining the quantity and distribution of participation during the teams’ critical question-and-answer sessions contributes to the field of research that explores team stress and decision-making, allowing us to view whether a SDWT of student engineers charged with making a collective decision would enhance their “group performance" (i.e. greater participation) or increase "centralization" of communication around a few key players.

III. Methods

In our full study we seek to observe and understand the specific role of face-to-face, verbal communication in the product design process of two separate student teams in Product Engineering Processes, a senior capstone mechanical engineering course at MIT. **In the first part of the study, which is presented in this paper**, we focused on how students approach communication as an essential team task by audio recording two critical design decision meetings, transcribing the audio files, and examining the transcripts for duration of product presentations and discussions, participation, question asking, and question answering.

A. Course Context

In the MIT mechanical engineering capstone course, students work in product design teams to propose ideas for new products, select a few for development and testing, and ultimately choose one, as a team, to build and test as an alpha prototype. At the end of the semester each team presents their prototype at a large event, akin to a product launch. While the team project exists in many engineering capstone courses, one way that MIT's course is unique is that individual student teams are atypically large, comprising 18-25 students. Enrollment in the course is 160-190 students every fall semester.

The student teams are near autonomous and self directed: students brainstorm and invent their own products, as well as lead their own meetings, during which they discuss work tasks, report progress, and make design decisions. Each team elects two students to serve as system integrators (SI), who convene meetings, coordinate agendas, and monitor communication and integration among task forces working on design elements. Other students are elected to serve in the roles of safety, information, tool, and financial officers. Engineering and communication instructors, as well as industry mentors, are present in an observational and advisory capacity.

Teams have weekly three-hour lab meetings that are "dedicated to the management of the project," and function to enable teams "to define the product development process," according to guidelines published by the lead professor[26]. Each team decides the length of time they choose to meet each week, sometimes staying for the full three hours, other times meeting briefly to exchange updates before working in the lab. While there are some broad guidelines for each weekly lab meeting of the team, teams understand that they are flexible, and the actual content of each lab meeting is coordinated by the SIs.

This capstone course is designated as communication intensive, and it is one option of a few required for the fulfillment of degree requirements in the major. In addition to two lab instructors, a communication lecturer is embedded with each team, primarily to provide feedback and suggestions before and after milestone presentations, as well as facilitate communication-based workshops throughout the course. While each student is expected to participate in a formal presentation during the term, there are no stated expectations regarding individual communication during weekly team meetings. Students have freedom to choose when, how, and if they verbally, visually, and nonverbally communicate during team meetings without the pressure of evaluation by an instructor.

B. Design Meeting of Interest

The particular lab meeting examined in this part of the full study was run by students on the two teams, with instructors present and contributing minimally, mainly as questioners. Known in the course as the "down-select meeting," the meeting's purpose is for a team to consider the four product ideas they have been developing in sub-teams and choose one for prototyping. Regarding the structure of the decision meeting, the teams received basic suggestions from the lead faculty during lecture and on the course website[27]:

> Prepare a short but informative presentation about the opposite section's** *two concepts*, highlighting strengths, weaknesses, risks, and open issues. Be sure to work with the other section and have their agreement on the key points of your presentation. In addition to summarizing the sketch models and mockups, please try to outline thoughts about key tasks that the team will engage in to carry an idea forward to a product prototype.
>
> [**Note: each section is half a full team and comprises two sub-teams. So, each large team, for the first half of the semester, is organized by students into four small sub-teams.]

The procedures and results presented in this paper focus on two teams' communication during a portion of their down-select meeting: the in-lab presentations and follow-up question-and-answer sessions for each of four product ideas.

C. Procedures and Materials

Recording of Team Meeting
This was a naturalistic study in which two communication instructors embedded on student design teams audio-recorded the team meetings; transcribed the recorded speech; and (as supplementary material) examined drawings and other informational materials produced in the meetings. Student identities in the full teams and in the sub-teams remained confidential. While instructors and professional mentors are customarily in attendance at these student team meetings

to give advice and ask questions, the instructors and mentors were not subjects in our study. The appearance of their remarks in the audio transcripts were flagged and redacted.

In the effort to preserve the natural state of team meetings and limit any disruption or unease on the part of students, non-invasive microphones were used to capture the recording (Figure 2).

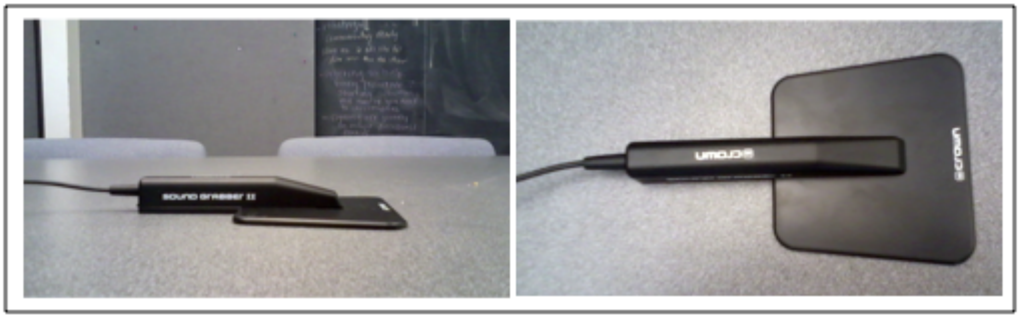

Figure 2. Recording apparatus. Two slim "Sound Grabber II" pressure zone microphones (Crown, Inc.) sat unobtrusively on the conference table to record the students' discussions.

Students sat around all four sides of a long, rectangular conference table (Figure 3). Microphones were placed in the center of each table half. Students spoke and behaved candidly as they had in prior meetings, using informal speech and engaging in side conversations, which demonstrated their low reactivity to the recording process. Because teaching assistants regularly photograph students in lecture and lab meetings for the course website, the students were already accustomed to the presence of recording devices amidst class activities.

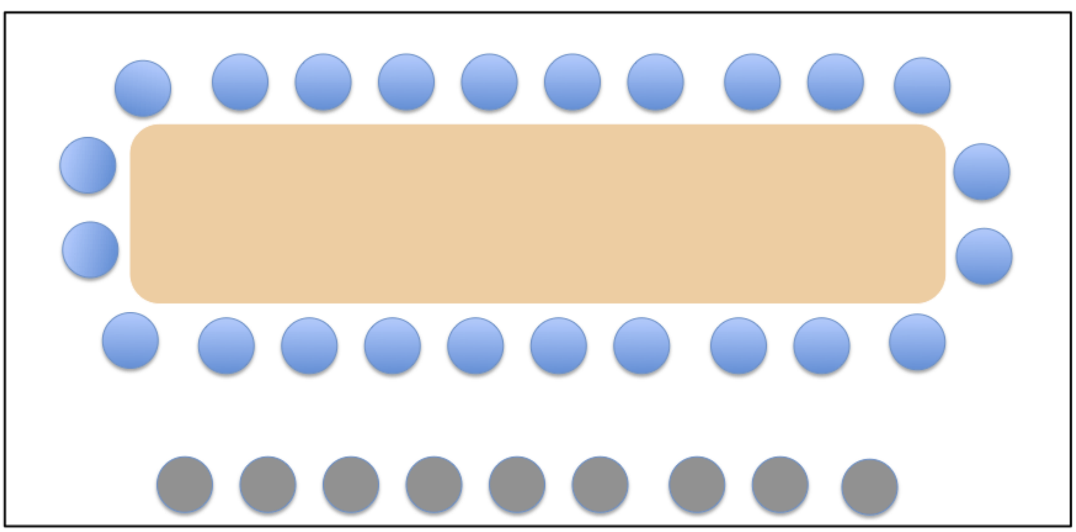

Figure 3. Diagram of the conference table arrangement for team meetings. The students (blue) sit around the table while the instructors (grey) sit along the periphery of the room.

Students on the two teams received and signed electronic participation request forms, and were not compensated in any way. Audio files of the recorded meeting were transcribed by CastingWords (castingwords.com), an online transcription service.

IV. Results

This first study, part of a larger project, examined the communication of students on two teams during a key product decision meeting: the down-select meeting, when each team chooses one product concept among four the students have modeled by working in four sub-teams. The meeting occurs at the semester's mid-point, and it is three hours in length, which is set aside and scheduled in the course syllabus for lab activities. For this study, we analyzed a portion of the transcript on the first segment of the meeting, in which team members gave presentations on each concept and held a question-and-answer session.

A. Duration of Product Presentations

In our examination of the audio recording and transcript of the decision meetings, we counted the time duration of the product presentations for both Team A (Figure 4) and Team B (Figure 5).

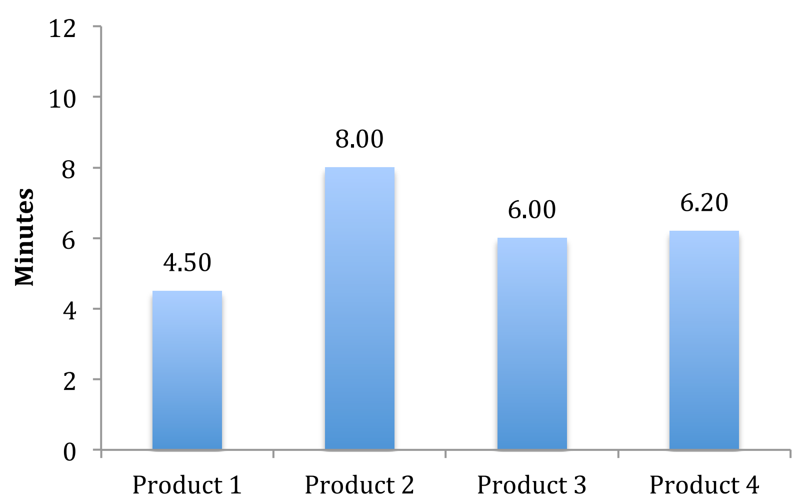

Figure 4. Duration of product presentations in meeting for Team A. Each sub-team of students delivered a brief presentation on another sub-team's product. All presentations were delivered with PowerPoint slides. Average duration was 6.18 min, and standard deviation was 1.43.

For Team A, the duration of presentations ranged from a low of 4.50 min for Product 1 to a high of 8.00 min for Product 2. Average duration was 6.18 min, and standard deviation was 1.43. The product that was selected at the end of the meeting, in a team vote, was Product 3; there is no correlation between duration of presentation and ultimate product selection.

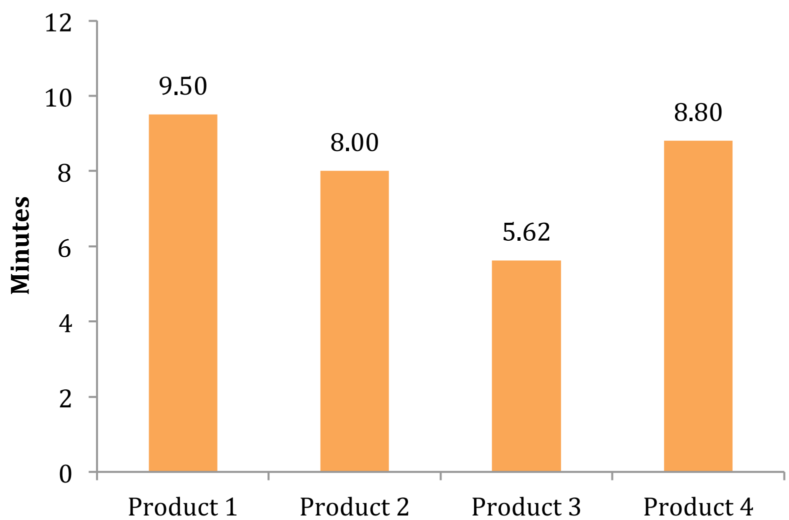

Figure 5. Duration of product presentations in meeting for Team B. Each sub-team of students delivered a brief presentation on another sub-team's product. Presentations were delivered with a combination of notes, handouts, and video. Average duration was 7.98 min, and standard deviation was 1.69.

For Team B, the duration of presentations ranged from a low of 5.62 min for Product 3 to a high of 9.50 min for Product 1. Average duration was 7.98 min, and standard deviation was 1.69. The product that was selected at the end of the meeting, in a team vote, was Product 4; there is no correlation between duration of presentation and ultimate product selection.

B. Duration of Discussion that Followed Each Presentation

In our examination of the audio recording and transcript of the decision meetings, we also counted the time duration of the Q&A discussion period that followed each product presentation for both Team A (Figure 6) and Team B (Figure 7). These periods varied greatly for both teams.

For Team A (Figure 6), the average duration was 4.74 minutes, and standard deviation 4.48. That the duration was highest for Product 3 at 11.2 min, the product ultimately selected for further development, suggests a correlation between duration of Q&A and product selection, which demands further study. The transcript indicates that the question-and-answer session for Product 3 ended only when the team's system integrator requested that they move on to the next product to ensure enough time remained in the lab meeting to discuss other options and reach consensus as a team.

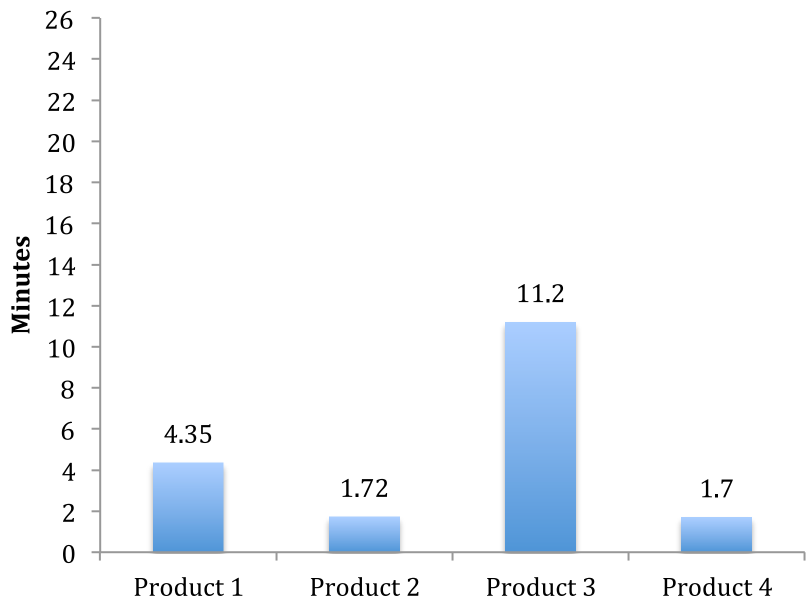

Figure 6. Duration of question-and-answer sessions for each of four products for Team A. The average duration was 4.74 minutes, and standard deviation 4.48. Product 3 was the concept eventually selected to develop as an alpha prototype.

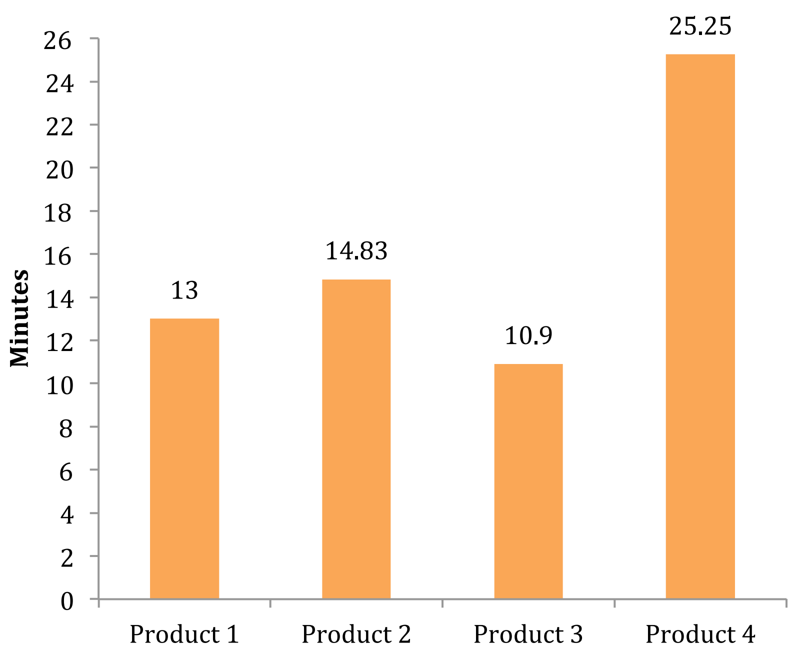

Figure 7. Duration of question-and-answer sessions for each of four products for Team B. The average duration was 15.99 minutes, and standard deviation 6.37. Product 4 was the concept eventually selected to develop as an alpha prototype.

For Team B (Figure 7), the average duration was 15.99 minutes, and standard deviation 6.37. That the duration was highest for Product 4 at 25.25 min, the product ultimately selected for further development, suggests a correlation between duration of Q&A and product selection, which demands further study. The transcript and audio recording indicate that, with the Q&A, the team exceeded the 25-minute limit that had been allotted for each product presentation and follow-on Q&A period by ignoring an audible alarm at 25 minutes.

B. Verbal Participation by Individual Team Members: Question Asking

In order to determine the quantity and distribution of verbal participation within each product discussion, the number of individuals who contributed by asking questions was also calculated (Figures 8 and 9). As with all lab meetings, there was no requirement for students to verbally communicate during the question-and-answer sessions, which revealed varying levels of voluntary participation by members of the team.

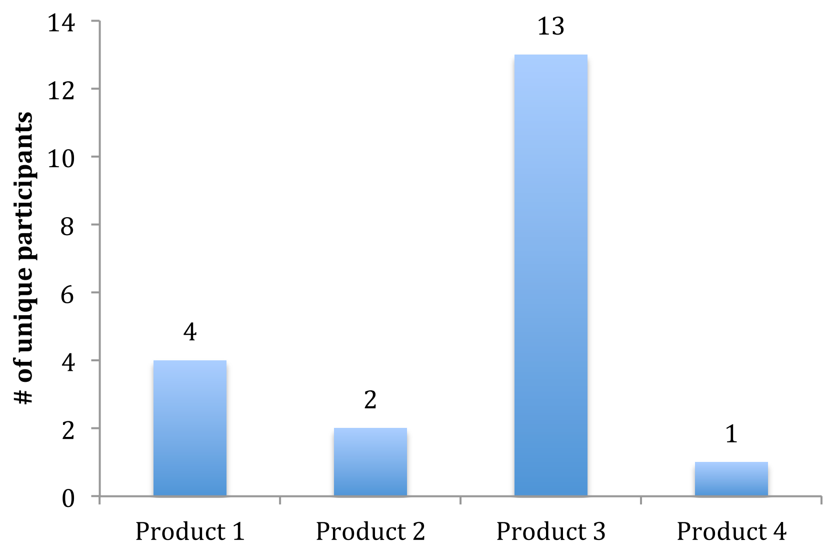

Figure 8. Number of individuals who asked questions during the question-and-answer session that followed each product presentation for Team A. Out of the 24 students on the team, 13 students participated by asking questions about Product 3, the one ultimately selected for further development.

In the meeting for Team A, as shown in Figure 8, the number of unique individuals asking questions ranged from a low of 1 individual for Product 4 to a high of 13 individuals for Product 3. Average number of individuals asking questions was 5.00 individuals, with a standard deviation of 5.47. Although not depicted in this graph, which displays unique individual participation, the transcript indicates that several individuals asked more than one question.

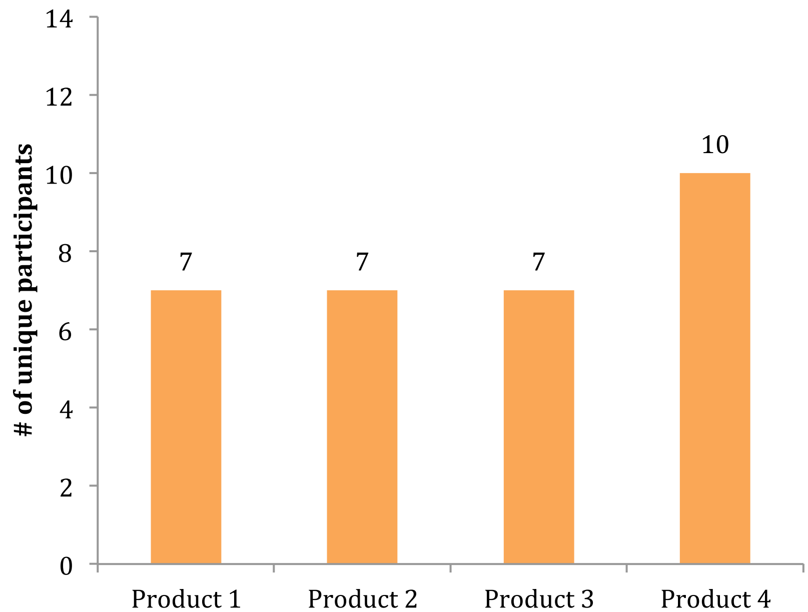

Figure 9. Number of individuals who asked questions during the question-and-answer session that followed each product presentation for Team B. Out of the 24 students on the team, 10 students participated by asking questions about Product 4, the one ultimately selected for further development.

For Team B's meeting, as shown in Figure 9, the number of unique individuals asking questions ranged from a low of 7 individuals for Products 1, 2, and 3 to a high of 10 individuals for Product 4, the one ultimately selected. Average number of individuals asking questions was 7.75 individuals, with a standard deviation of 2.25. Although not depicted in this graph, which displays unique individual participation, the transcript indicates that several students asked more than one question each about Product 4, including one who asked 5 and one who asked 11.

C. Verbal Participation by Individual Team Members: Answering

The number of individuals who contributed by answering questions was also calculated (Figures 10 and 11). As in question asking, this type of communication revealed varying levels of voluntary participation by members of Teams A and B.

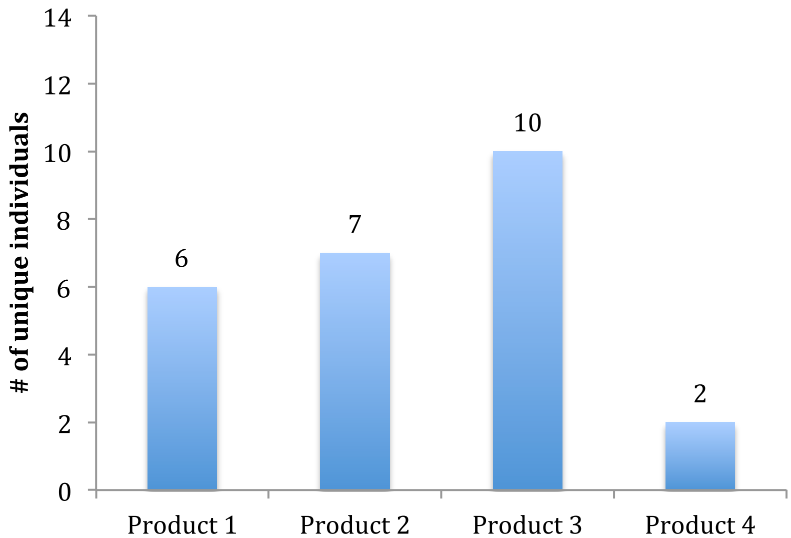

Figure 10. Number of individuals who answered questions during the question-and-answer session that followed each product presentation for Team A. Average number of individuals answering questions was 6.25 individuals, with a standard deviation of 3.30. Out of the 24 students on the team, 10 students answered questions about Product 3.

For Team A, shown in Figure 10, the number of individuals answering questions ranged from a low of 2 individuals for Product 4 to a high of 10 individuals for Product 3. Average number of individuals answering questions was 6.25 individuals, with a standard deviation of 3.30. Since the members of each sub-team held the most knowledge particular to their respective product, the transcript shows that they tended to supply most of the answers to questions asked about their product. For Product 3, 6 of the 10 students who answered questions were part of the sub-team, and 4 students were not. The 6 students who supplied answers to questions about Product 3 did so more than 1 time each.

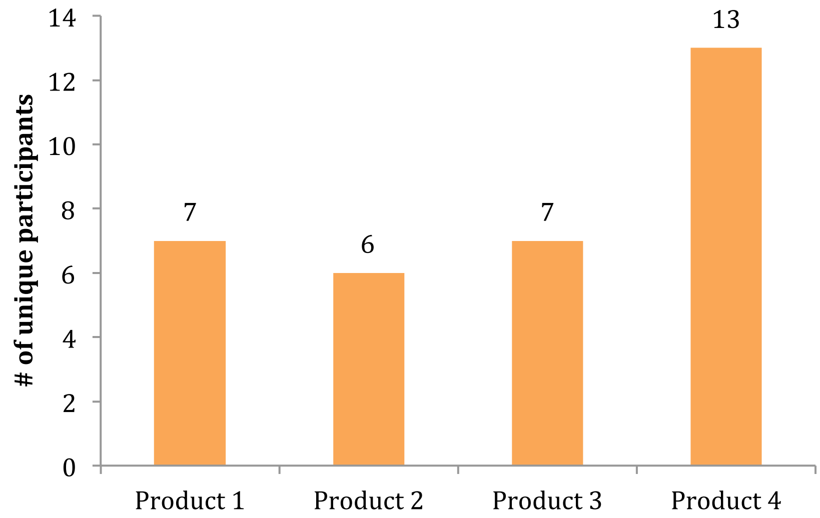

Figure 11. Number of individuals who answered questions during the question-and-answer session that followed each product presentation for Team B. Average number of individuals answering questions was 8.25 per product discussion, with a standard deviation of 3.20. Out of the 24 students on the team, 13 students answered questions about Product 3.

For Team B, shown in Figure 11, the number of individuals answering questions ranged from a low of 6 individuals for Product 2 to a high of 13 individuals for Product 4, the one ultimately selected. Average number of individuals answering questions was 8.25 individuals, with a standard deviation of 3.20.

D. Overall Verbal Participation by Individual Team Members

In order to observe overall participation in the unscripted Q&A discussion that followed each idea presentation, the total number of unique individuals who either asked or answered a question during a product Q&A was tabulated from the transcripts for both Team A and B (Figures 12 and 13).

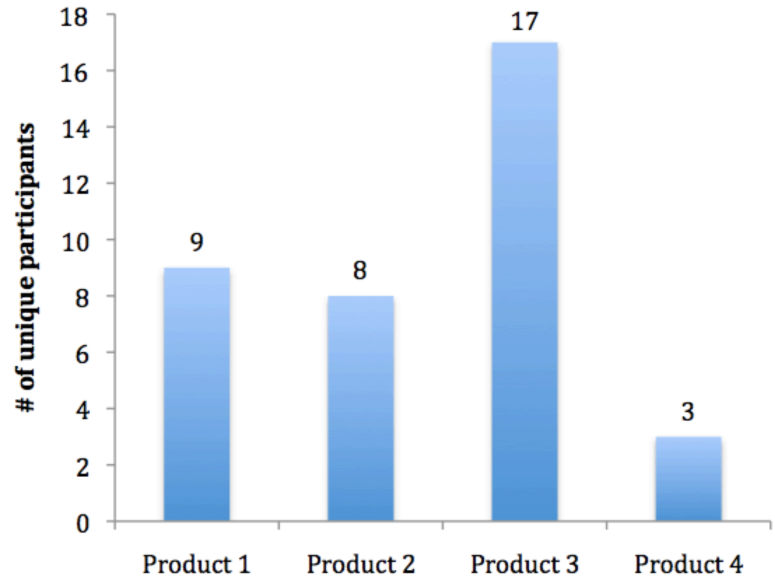

Figure 12. Number of individuals who participated in the question-and-answer discussions for each product in Team A. The discussion of Product 3 generated participation from the greatest number of team members, 17 out of 24.

For Team A, shown in Figure 12, the number of unique individuals who participated in the question-and-answer sessions ranged from a low of 3 individuals for Product 4 to a high of 17 individuals for Product 3, or about 71% of the full team. The average number of individuals participating in the discussions was 9.25, with a standard deviation of 5.79. We also tabulated from the transcript that a combined total of 23 individual students out of 24 students on Team A, or about 96% of the team, asked and/or answered questions during the question-and-answer sessions throughout the meeting.

For Team B, shown in Figure 13, the number of unique individuals who participated in the question-and-answer sessions ranged from a low of 9 individuals for Product 2 to a high of 16 individuals for Product 4, or about 67% of the full team. The average number of individuals participating in the discussions was 11.75, with a standard deviation of 2.99. We also tabulated from the transcript that a combined total of 20 individual students out of 24 students on Team B, or about 83% of the team, asked and/or answered questions during the question-and-answer sessions throughout the meeting. Note: because of audio quality of transcripts for Team B's meetings, a total of 7 contributions for Product 1 and 1 contribution for Product 4 could not be attributed to an identifiable team member. The contributions may have been made by already counted individuals or by different ones.

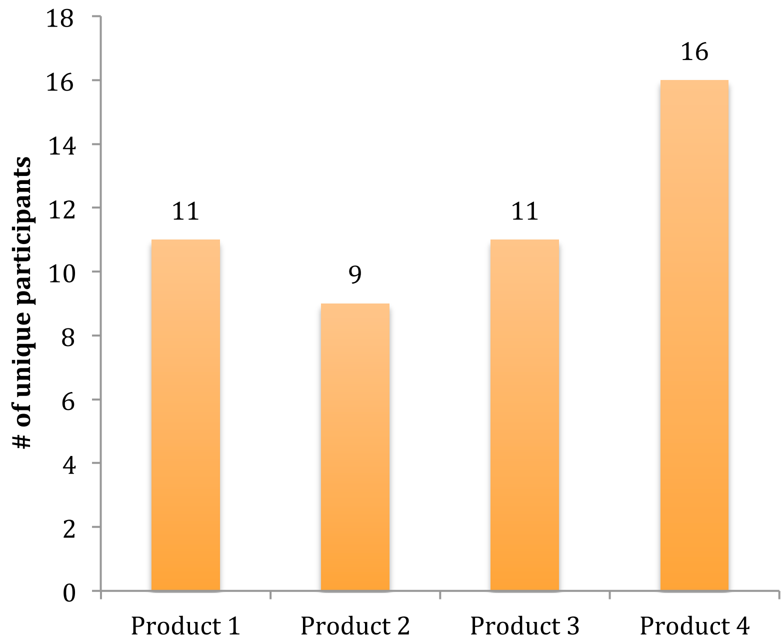

Figure 13. Number of individuals who participated in the question-and-answer discussions for each product in Team B. The discussion of Product 4 generated participation from the greatest number of team members, 16 out of 24.

V. Discussion

Educators and scholars have identified the decision-making processes of teams as an important area for both research and curriculum modification. Teams are the basic organizational structure in both industry and business, and educators assign team projects to promote peer learning and ready students for their professional lives. While decision making is critical to team performance, the social aspects of team decision making have received insufficient attention. As communication lecturers embedded in undergraduate engineering courses, we have observed that communication is at the heart of team social interactions. We are particularly interested in the role of communication for design decisions within the self-directed work teams (SDWTs), each made up of 20 or more undergraduates, in a senior capstone course in product design at MIT. In the first part of a larger study, we audio recorded, transcribed, and analyzed a portion of an important design decision meeting in which a student team presented and evaluated four different product ideas.

In the course guidelines, teams were advised to follow a consistent format in making short presentations on each of four concepts for discussion. The duration of each presentations (Figures 4 and 5) indicates that the four sub-teams for each of Team A and B making each presentation were reasonably compliant with guidelines. The average duration of presentations for Team A was 6.18 min (SD 1.43) and, for Team B, 7.98 min (SD 1.69). Both transcripts show that teams aimed for brevity and did not interrupt presenters, as advised. Team B, furthermore, imposed a 25-min limit total for presentation and Q&A session for each product idea. This behavior may suggest that student SDWTs, although given liberty as to the organization and tasks of their team, are inclined to follow clear process guidelines that scaffold a challenging task in which the outcome is not a given.

Due to the recommended constraints of the presentation portion of the meeting, we were more interested to examine the variations in discussion time (Figures 6 and 7) and participation among the more free-form question-and-answer sessions (Figures 8 and 9). The question-and-answer sessions allowed students to raise new questions and probe the team for additional information about available technical and user information as well as future possibilities for each product.

There was great variance in the duration of discussion after Team A's four product presentations (Figure 6), from a low of 1.70 min for Product 4 and 1.72 min for Product 2 to a high of 11.20 min for Product 3. A similar variance was noticed in the duration of discussion for Team B's four product presentations (Figure 7), from a low of 10.90 min for Product 3 to a high of 25.25 min for Product 4. (The duration of Q&A for Product 4 even superseded the time limit the team had imposed on their meeting agenda.) These results suggest that the team demonstrated a high level of team "energy" and "engagement" in the unscripted Q&A for the ideas that Team A and Team B chose over their three other ideas. Pentland measures the energy of a team by "the number and the nature of exchanges among team members"[8]. While energy refers to the quantity of communication exchanges, team "engagement" refers to the distribution of energy among team members[8]. The concepts of energy and engagement can be viewed as products of a "proactive cycle," in which members "engage in sequential patterns of proactive communication," which Kauffeld interprets as expressions of a positive group mood"[5,6]. The results suggest that the team's energy and communication engagement during the question-and-answer session indicated the students' intellectual and creative investment in the specific product, even though a preliminary look at the transcripts of both team meetings does not show an explicit proposal to select Product 3 by Team A or Product 4 by Team B from among the group of four ideas.

Particularly in the question-and-answer session for the products ultimately selected, the majority of members on both teams asked and/or answered questions for a productive and energetic exchange of information and ideas. This high distribution of team involvement indicates that the potential for "communication loafing" was dramatically reduced during this discussion, possibly due to the stated purpose of the meeting as a collective decision-making event, which provided clear motivation. As indicated in the Results section, on Team A a total of 23 out of 24 individual students asked and/or answered questions during the four question-and-answer sessions. On Team B, 20 out of 24 individual students participated in the four Q&A sessions overall.

Notably, a total of 17 individual students on Team A participated in the question-and-answer session for Product 3 (Figure 12), significantly higher than student participation in the respective discussions for Product 1 (9 students), Product 2 (8 students), and Product 4 (3 students). The stress and emotion of the meeting may have contributed positively to members' participation. A similar correlation was noted for Team B (Figure 13), where 16 out of 24 students participated in discussions for Product 4, with somewhat fewer for Products 1, 2, and 3. The team-wide impact of the impending product decision – each team knew that they had to reach consensus for a single product choice – seemed to decentralize communication and spread responsibility more liberally across the team during the meeting.

Based on Team A's decision to pursue Product 3 and Team B's decision to pursue Product 4, the students' high level of voluntary communication during the meeting might have served as an indicator of group interest and therefore a predictor of the final product selection. These findings may have implications for academic and professional SDWTs, as team energy and engagement during certain communication events, that can in part be measured by duration and number of participants, may serve as a potential indicator of future group decisions. In terms of possible applications for traditional, non-self-directed teams, the quantity and distribution of questions surrounding a design may be useful for managers to determine the focal point of their workers' enthusiasm and curiosity. For example, if a team is weighing several design ideas, the quantity and distribution of communication during the discussion of each design could indicate whether the team has shifted toward a unifying decision. In classrooms, the preponderance of students' questions, often viewed in part as a lack of understanding or evidence of confusion, may also indicate a heightened desire to invest a greater amount of intellectual energy in the particular topic.

Early findings from this study suggest that student SDWTs may rely on basic guidelines, which offer a kind of template, to scaffold a challenging, high-stakes meeting. Furthermore, the same teams will simultaneously demonstrate their level of energy and engagement in a potential pathway in both the time devoted to unscripted discussion and the degree of participation by individual team members in asking and answering questions. The scope of this first study is limited, however, in that it only focuses on a single decision-making event and does not take into account more discussion events at other points in the semester or design process. Nevertheless, early findings encourage further analysis of time devoted to components of a decision-making meeting, participation levels of individual team members in the unscripted Q&A discussion session for each idea proposed, and a rhetorical analysis of the unscripted discussions in decision meetings.

VI. Future Directions

In typical student teams working on group projects at the secondary and university level, collective decisions are most often made during team meetings held outside of the classroom. The design of the MIT mechanical engineering capstone course Product Engineering Processes, which is the context for this study, provided a unique opportunity for the naturalistic observation of communication in student-led self-directed work teams (SDWTs), since collective decision making events occur in the presence of instructors and mentors. This initial study, although limited in scope, looked at the duration of time given to idea presentations in a decision-making meeting, and the level of individual participation in the unscripted discussion portions that occurred after each product presentation. Early findings suggest that (a) teams rely on basic guidelines as a template for an equitable presentation of four different ideas, and yet (b) demonstrate varying degrees of energy and engagement with particular products, as shown in the duration of and team participation in the unscripted discussions that follow each scripted presentation.

Future analyses of the data for two teams in the course will focus on the following areas:

- The specific types of questions asked during the decision meeting (e.g. affirming, critical, clarifying, procedural, exploratory).
- The students' perceptions of the decision-making process and explanations of their own communication choices as expressed in interviews conducted after the decision meeting.
- The language or rhetoric used to make proposals and add information and evidence, particularly in statements made during the discussion that were not overt questions or answers.
- The role of nonverbal communication in the decision making process, particularly since students in interviews noted the importance of behavioral cues in affirming that others heard and understood what they said.

Building upon this initial study, our future analyses of the communication data collected may offer guidance to educators in designing course-based team experiences that are analogs to the communication and decision-making challenges encountered in the workplace. These findings may inform engineering instructors seeking to balance explicit faculty instruction with a greater degree of team autonomy during the design process.

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