CHARACTERIZATION OF LEADERSHIP WITHIN UNDERGRADUATE ENGINEERING DESIGN TEAMS THROUGH CASE STUDY ANALYSIS

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ABSTRACT

The paper explores leadership that exists within undergraduate engineering design teams. Often, leadership is described based on managerial styles, leadership types and styles, emotional intelligence, and work climate. However, little work explores leadership specifically within engineering and educational environment. The motivation of this research is further inspired based on the researcher's own experience in undergraduate engineering design teams and the lack of formal leadership structure and training in typical engineering education programs. Leadership is identified in this research through conducting case study research by examining two undergraduate engineering design teams addressing different projects in different course settings. The results and conclusions from each study are extracted by triangulating within and across each of the data collection methods. Through these two case studies, leadership is clearly found present in both cases and with task-oriented leadership being the more prevalent type.

MOTIVATION

The objective of this research is to identify how leadership affects engineering design projects. While it is generally well accepted that project success can depend heavily on good management and leadership, little clear instruction is provided to students about these topics. Further, the literature is sparse with respect to what types of leadership are appropriate or even commonly found in engineering design teams. Therefore, two case studies are completed to understand the role of leadership student design teams. This is descriptive research; a necessary first step before prescriptive guidelines and recommendations can be appropriately developed. In the first case study, senior design students enrolled in a capstone design class and coached by a graduate student (the first author) were challenged with designing a crimping device for installation of the seal on a sport activity vehicle's rear-hatch in an industry sponsored semester long project. In the second case study, faculty, graduate, and undergraduate students designed and built a large system for soft soil off-vehicle endurance testing of tires. These case studies explore how leadership is perceived, influenced, and defined in undergraduate engineering design projects.

Many universities seek to continually improve their capstone design courses to develop better team building and leadership within each group [1-3]. Engineering educators have also conducted self-assessments to determine whether the amount of leadership learned in the course is satisfactory [4-6]. In contrast to leadership, team-building exercises have been the focus of some researchers development of capstone coursework [7,8]. Lastly, efforts are underway to understand the best method to form teams [9,10] and identify who should be the team leaders [11]. Personality tests [12-15] or general individual questionnaires [16] have been used to create teams but they have not targeted the cultivation of leadership in undergraduate capstone projects nor evaluated the realized leadership. Therefore, this work addresses the research question:

> *Can leadership be found within undergraduate capstone teams?*

This work seeks to find existing leadership in student design teams without any intervention strategies. Therefore, structured case study research methods and tools will be used. Moreover, these tools will be evaluated and recommendations formed for which data collection methods provide better approaches for studying leadership in student design teams.

LITERATURE ON LEADERSHIP

Task and Interpersonally Oriented Leadership

Early research based on gender influence on leadership traits identified task and interpersonal leadership styles [17]. These types differentiates themselves by the primary actions used to manage teams. Task oriented leadership is associated when goals are defined towards accomplishing the required tasks of the project. Behaviors exhibited in this style include having team members follow the rules and procedures, maintaining high standards for performance, and abiding by the structure established by the leader. Interpersonally oriented leadership is where the emotions and morale of the team members are assessed on a regular basis allowing the leader to connect and understand each individual within the team. This approach to leadership develops trust and considers the welfare of the team members to build cohesiveness and relationships so the team works better.

Transactional and Transformational Leadership

From the initial study of the Multifactor Leadership Questionnaire (MLQ), there were seven factors of leadership derived [18]. These factors include charisma, inspirational, intellectual stimulation, individualized consideration, contingent reward, management-by-exception, and laissez-faire leadership. These factors were broken into two arenas of leadership: transformational and transactional. Many researchers have sought to find relationships between these factors of leadership and personality types [19-21]. Tests such as the Five Factor (Big Five) Personality Test, Myers-Briggs Type Indicator, and the NEO Persoality Inventory have found personality types and these authors are linking them to existing leadership styles. The effects of gender on leadership have also been researched [22-24] and the changes in organizational structure [25-26] have been derived from studies on transactional and transformational leadership. While interesting, it does not appear that there has been a focus on determining what types of leadership are actually in evidence during undergraduate design projects. Thus, this research is a first step towards addressing this gap in the literature.

RESEARCH HYPOTHESIS

Based on results of previous studies, changes in the curriculum have been recommended to increase leadership skills in undergraduate capstone teams through team building exercises and leadership development tools. More promise has been shown in team formulation techniques that take into account the student's interaction within undergraduate capstone teams. The two case studies conducted in this paper establish patterns leadership within engineering capstone groups by evaluating the team members. By using three methods of qualitative and quantitative data collection, the results found will determine whether there are inferences of existing leadership that can be supported within or comparatively against each case study. The specific hypothesis of this research is:

The leaders of the group will clearly be identified by the team members.

If this hypothesis is clearly supported, then subsequent research can investigate the causes for different types of leadership evolution in undergraduate teams. Eventually, this work will lead to definition of specific strategies to equip students with the necessary skills and experiences in leadership to be success in design projects at both the undergraduate level and in their future professional careers.

OVERVIEW OF CASE STUDY RESEARCH

Well-developed experiments, tests, or trials with clear analysis of these methods yields sound data and provides clear solutions. However, a well-constructed case study yields clear results with many types of methods that provides more substantial analysis of exploring problems too complex to experimentally study. Case studies are a means of which methods are used to explain complex phenomena within a natural environment [27]. These methods require both qualitative and quantitative analyses with multiple views to triangulate data. The triangulation supplies the robustness of the interpretation of the data, thus providing increased confidence based on accuracy. Figure 1 shows how triangulation in this research is employed through multiple methods supporting each other and internal triangulation with multiple data views for each method.
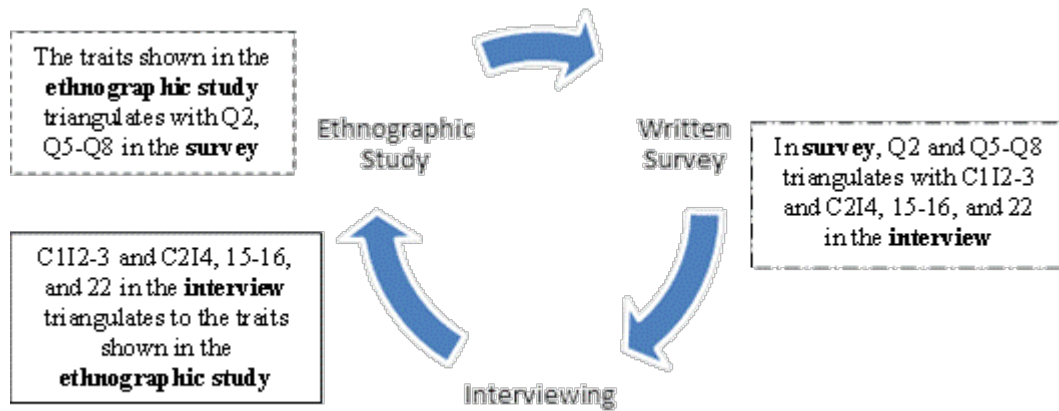
Figure 1. Case Study Triangulation

Engineering Case Study Examples

Case study research in engineering design has led to insights in design method development, design tool development, and the application of prototyping. Case study research to identify patterns which constitute a framework for research and development of systematic design methods [28,29]. Multiple case studies internally and externally allowed the research to gain patterns and develop those conclusions. There are many examples of case studies used in engineering [30-32], and case studies which specifically involve the examination of team formulation issues in engineering [33-39]. Table 1 shows a description of examples case study research in design.

Data Collection Methods

Various data collection methods may be used to extract case study data. First, an ethnographic study is where the researcher is embedded within a particular situation, group dynamic, or culture to study complex characteristics to expose classifications and patterns [40]. For example, if the researcher desires to understand the design process of a company, then the researcher assumes a design role within the company [41,42]. Interviewing is a question and answer process where the researcher receives information from individuals on targeted topics [42]. Questions created for interviews should be centered on the information needed to help answer research questions. These questions can be structured or free, depending on how much is understood *a priori* and whether the interviews are replicated with other individuals. Surveys are similar to structured interviews in written form and without the researcher as an interrogator. There are two types of written surveys used in this research: evaluations and questionnaires. Within a questionnaire, the Likert scale often is used as a technique to gauge how strongly individuals agree or disagree [43].

CASE STUDY OF LEADERSHIP

Two undergraduate case studies will be explored here: the design of a tool for a manufacturing installation process (Case Study 1) and the design and construction of a large scale tire testing system (Case Study 2). Case Study 1 will use ethnographic data, observatory study, written survey, and interviewing. Case Study 2 will use two written surveys, observatory study, and interviewing. Case Study 1 has a longitudinal study where the other three sets of data compliments the evolution of the design process. Case Study 2 implements a retrospective evaluation sheet that encompasses the leadership and emotional traits exhibited over the project's span.

A complete collection of the questions that are found in the interviews, surveys, and evaluation forms may be found in [44]. For brevity, these questions are coded in this paper as Case Number-Collection Type-Question Number. For example, Question 6 from the interview in the Case Study 1 is known as C1I6 and Question 3 from the Case Study 2 in the questionnaire is C2Q3. There are six interview questions in Case Study 1 and 28 in Case Study 2. In Case Study 1, there are four team members in the group assigned gender appropriate names Alex, Barry, Carol, and Dave to ensure anonymity in the research. In Case Study 2, the five team members were named Eric, Fred, Grace, Hank, and Irene.

Each name is gender appropriate, though gender and leadership correlations are out of scope of this research.

Table 1. Summary of Case Study Research

Ref	Research Question	Case Study Description	Research Outcome	Research Area(s)
[10]	N/A	A review of standard and current practices of capstone education	Project sponsors accept the course but the faculty has mixed reviews	Engineering Education
[11]	How much do engineering design teams consider social interactions?	Two ethnographic studies conducted to evaluate teams	A model created for effective teamwork	Engineering Design, Eng. Education
[28,29]	Can patterns develop by establishing a framework of systematic methods?	Two cases, internal and external of the cases studied	Creation of model which develops systematic methods	Engineering Design
[30]	How does information flow through multiple design processes?	Three cases tested and verified the DEIM method	Method helps suit the process to the design problem	Engineering Design
[31]	Can components be standardized through the evaluation of production systems?	Case study used as example for using standardization	Effectiveness and performance of the method excelled	Engineering Design, Manufacturing
[32]	Which variables affect learning assistance in engineering design?	Evaluated each design variable through cases	Found learning assistance to be a powerful tool	Eng. Design, Eng. Education
[33]	Which product development methods are the most beneficial?	Two companies were analyzed through 3 variables	New product dev. methods reduced workflow steps	Manufacturing, Concurrent Eng.
[34]	Which problem-based learning methods provide better success?	Two contexts of problem-based were assessed	Seven recommend. were made to enhance design	Engineering Design, Eng. Education
[35]	Will the implementation of problem-based learning enhance the engineering curriculum?	Two cases of courses to assess the use of PBL	Prelim. assessing showed initial difficulties in PBL	Engineering Design, Eng. Education
[36]	Can a framework be developed from decision criteria of performance measures?	Two cases are used to investigate the use of framework	The framework can lead to more suitable selections	Eng. Education, Mechanical Eng.
[37]	How can personality inventories be used for group selection?	Case study carried out with multiple personality groups	Recommended using MBTI for diverse groups	Engineering Education
[38,39]	Is using a web-based system better than using an instructor's criteria for assigning members?	Team-Maker and faculty selections were compared	Web-based system recommended for team selections	Engineering Education

Case Study 1: ME 402 Design Team

Overview

This case study is set within an undergraduate senior level capstone design course at Clemson University. A group of four students worked four months to develop a crimping system for the rear hatch of their sports utility vehicles in an industry sponsored project. Each student was a senior

mechanical engineering major at Clemson University yet they did not know each other well before the start of the project. A graduate student coach (the first author) was assigned to the team to help them progress through the design process where necessary. The graduate coach was able to observe directly the leadership traits and characteristics of the students throughout the project. This provided an opportunity for the graduate coach to perform the ethnographic study once per week during their meetings to determine each group member's task and interpersonally oriented leadership. The characteristics for task and interpersonally-oriented leadership (Work Completion, Delegating Tasks, and Individualism for Task and Inspirational Motivation, Idealized Influence, and Individualized Consideration for Interpersonal) were marked each time a team member exhibited them during the weekly meetings. Additionally, a questionnaire was given to the team members at the end of the project. The questionnaire consisted of eight questions that asked about leaders seen in the group, their leadership and confidence, and their knowledge base on leadership. Lastly, the interview of six questions was administered to the team members.

Results

In the ethnographic study of Case Study 1, leadership is revealed directly through the accumulation of traits seen in each team member. Carol and Dave demonstrated the most traits associated with both task oriented and interpersonal leadership activities (Figure 2). They each showed an amount which was more than the other two team members combined. Carol is defined as a task-oriented leader and Dave is a balanced leader who shows slightly more occurrences of interpersonally oriented traits. Next, the leadership questionnaire revealed similar results to the ethnographic analysis. The team members were asked if there were clear leaders that arose in the project (C1Q2). Carol was identified as a leader by every team member and Dave was seen as a leader by three of the students. Students were asked to rate
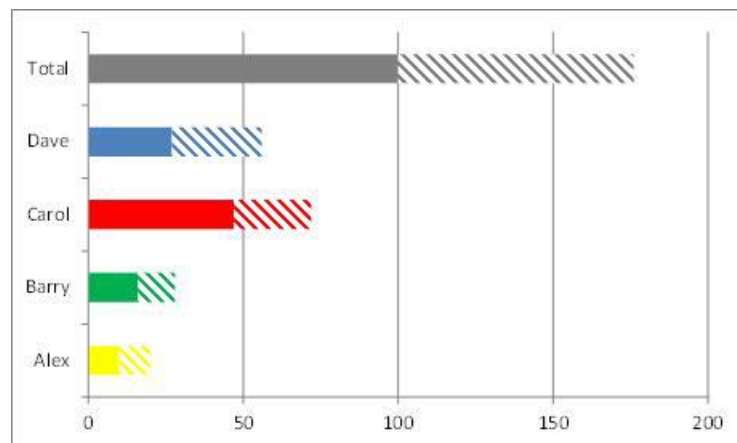

Figure 2. Ethnographic Study Results (Solid is Task Leadership and Dashed is Interpersonal)
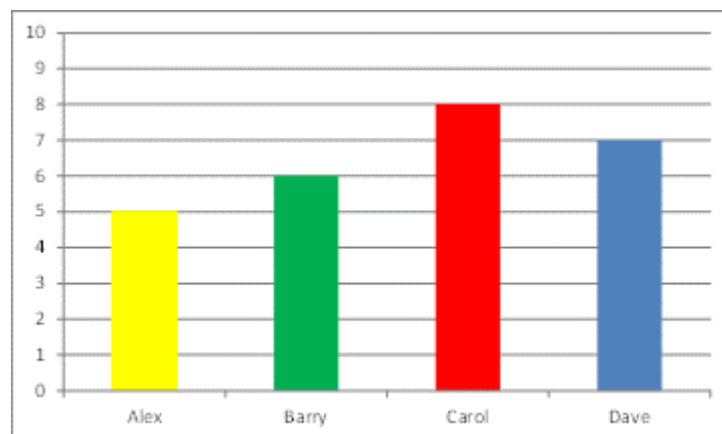

Figure 3. Question C1Q6: Confidence of how others perceive ones' self as a leader (10 is extremely confident)

how they feel others perceive them as leaders (C1Q5 and C1Q6) and how they view themselves as leaders (C1Q8). All students stated that they are viewed by their colleagues as a leader (C1Q5). In C1Q6, the confidence that others view them as a leader was measured (Figure 3). It is seen that Carol, while exhibiting the most leadership characteristics from the ethnographic study also believes the strongest that her colleagues view her as a leader. The rank order between how the amount of leadership characteristics observed and the confidence that others viewed them as leaders agree. This suggests that leaders can self-identify in undergraduate teams.

However, when asked to rate themselves in terms of their leadership ability (C1Q8), Dave had the highest self-assessed leadership ability, Barry and Carol had the next highest, and Alex had the lowest (Figure 4). All students rated themselves as above average (value of 5) leaders. In this case, Carol is not as confident that she is a capable leader, despite the fact that she recognizes herself as a leader.

In the interviews, Carol and Dave were both identified by all team members as the primary leaders. When asked about how they each contributed to the team, Carol said that she set "deliverables and tasks for each meeting". This aligns with the task oriented leadership characteristics that were observed by the graduate coach. This suggests that the student leaders not only recognize that they are leaders, but they can self-identify what type of leader they are. Dave responded in the interview that he "keeps all the information organized and standardized the e-mails". This
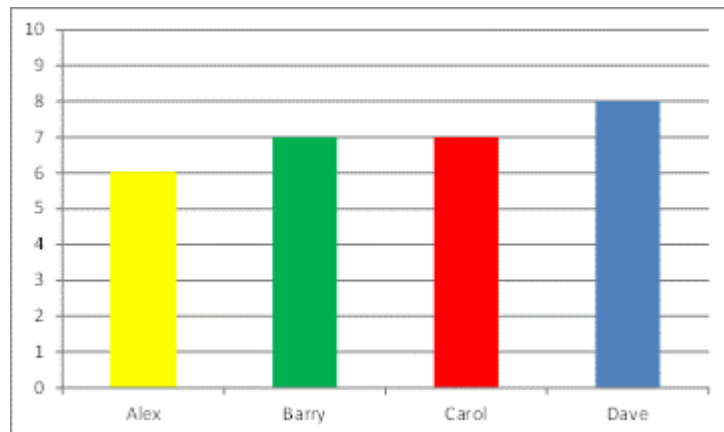

Figure 4. Question C1Q8: Self assessed ability of leadership (10 is very strong, 5 is average)

activity of ensuring that all information is shared with the team members is both task oriented (process focused) and interpersonal (checking to ensure that everyone is kept abreast). Both Alex and Barry recognized that Carol and Dave were the primary project managers.

In conclusion, from the three data collection methods, multiple facts are inferred. Carol and Dave's amount of leadership shown in the ethnographic study are at least double the amount of Alex and Barry's tally. Carol and Dave were seen as leaders in C1Q2. Carol's confidence wavered from 8 in C1Q6 to 4 in C1Q8, but Dave's confidence is consistent at values from 7 in C1Q6 to 9 in C1Q8. Finally, Carol and Dave both commented on leadership roles in the interview while Alex and Barry focused on the project. Thus, Carol and Dave are clearly defined as the leaders in Case Study 1.

Case Study 2: NASA Lunar TWEEL Project

Overview

The second case study was done on a yearlong undergraduate design project in which a lunar wheel endurance testing device was designed and built. This endurance testing device is for a NASA funded project to test the long-term capabilities of a Lunar non-pneumatic tire [43]. The Lunar non-pneumatic tire is designed for lunar rovers with a travel life of 10,000 km [44]. This project part of a larger collaboration with NASA's Jet Propulsion Laboratory, Michelin, and Clemson University.

The student design team consists of five mechanical engineering undergraduates. These students are a part of the Creative Inquiry group, which is a voluntary opportunity for undergraduates to gain more experience with team projects in their respective fields. Unlike Case Study 1, the team also includes graduate students and a professor who actively work with the team in doing the project, not serving only as managers and coaches. The primary direction of the project is set by the professor. For this case study, two written surveys and an interview were

Table 2. Summary of C2I4

Student	Number of Projects	Number of People in Projects	Amount of Money Spent within Projects
Eric	50+	2 – 20	$1000 – 2M
Fred	2	2, 4	$26 – 28
Grace	5 – 6	3 – 4	$0
Hank	2	3, 5	$100
Irene	3	3 – 7	$100

implemented. An evaluation sheet was given to each of the team members to assess leadership traits as found in the literature. To compare the students on this project to that of Case Study 1, students were asked about their previous design experiences. Table 2 illustrates the past experience that each of the students had in previous engineering projects. Eric's experience clearly was the most out of the group. Eric is the only outlier when comparing the team experiences with those from Case Study 1.

Therefore, we can conclude that the sample population for these two case studies are comparable, though not identical.

Results

The interview questions were internally triangulated to ensure consistency of student responses. The first question was to determine the students' self-identified roles in the project (C2I4). To triangulate these responses, students were asked about what they activities and deliverables they documented (C2I5) and how they specifically contributed to the project (C2I9). The frequency of the documentation was also reported (C2I6). The documentation activity is used as a surrogate for task-oriented leadership. Eric, Fred, and Irene said they recorded documentation either from "week to week", "every week", or "once a week". Conversely, Hank says that work was recorded "bi-weekly" and Grace says "just once". This suggests that for overall effort, Hank and Grace were lower than the other three and likely would not be recognized as task-oriented leaders.

C2I15 and C2I16 ask

When asked whether the students noticed any of their team members not taking initiative (C2I15) or if they had seen any unmotivated individuals (C2I16), Eric, Fred, Grace, and Irene all agreed that Hank did not take any initiative. This supports the statement that Hank documented work only "bi-weekly" as a surrogate for low contributions. It would be expected that based on this lack of effort and initiative, Hank would not be recognized as a leader.

The students were asked if any team members had taken "ownership" of the project (C2I22). Grace and Hank were not identified by any students as taking ownership over the project. On the other hand, Eric called ownership "making sure that the parts (he) was responsible for matched the designs" (a task-oriented trait) and Fred "invested time and effort into the project" (an interpersonal-oriented trait) and says "if that means seeing the project through completion" (a task-oriented trait). From the interview, there are indications that Eric and Fred could be the leaders of this group.

In the questionnaire, the same eight questions were asked similarly to the previous case study. Students were asked to identify the leaders on the team (C2Q2). Irene was identified as the team leader twice as often as Fred and Eric while Grace and Hank were never identified (Figure 5).

When asked if they think other students within the group perceived themselves as leaders of the group (C2Q5), Eric, Fred, Hank, and Irene all believed that others thought they were leaders. This suggests that Hank had some belief that he was a leader when others did not. Thus, when evaluating the responses of Hank to other questions, one is required to question his veracity.

Team members were also asked whether they saw themselves as primarily a leader or a follower (C2Q7). Eric and Fred were the only ones that stated that they were leaders. This is in conflict with the fact that Irene was identified by her peers most frequently as a leader. Therefore, students' definitions of what a leader is may not align or Irene may have a lower
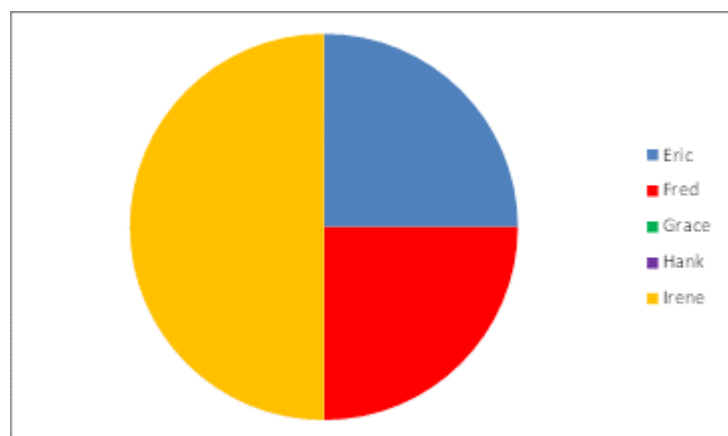

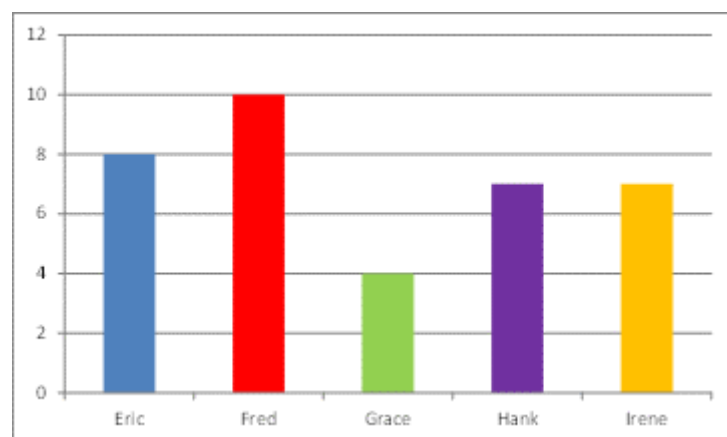Figure 5: Peer Identified Leaders (C2Q2)

Figure 6: Self Assessment of Leadership Ability (Question C2Q8)

opinion of herself than her colleagues have of her. This is explored further in C2Q8 which asks each student to self-assess their ability as a leader (Figure 6). Eric and Fred, again viewed themselves as strong leaders while Irene did not have confidence in her leadership ability. This raises the question about whether students who perceive themselves as leaders are more valuable to the team. This is reserved for future investigations, but self-efficacy with respect to leadership traits seems to be important.Through two methods, Eric and Fred have shown indications of their leadership. However, as a more experienced teammate, expectations of confidence are higher for Eric than all other team members. Yet, that is not found in Case Study 2. Therefore, experience and confidence are not clear indicators of leadership ability or assumed roles.

Lastly, an evaluation sheet was used as a quantitative measure of leadership within the group. Each team member rated the other members on leadership traits found in transformational and transactional leadership. The scale ranged from 1 (strongly agree) to 5 (strongly disagree). Each team member also conducted a self-evaluation to compare to the averaged values of their counterparts. From the evaluation, Irene and Grace had the two highest evaluations within the group. Irene was also the student with the most accurate self-evaluation compared to the average values of the other four students. This is interesting in that she was also clearly a leader while she did not identify herself as the leader. A possible explanation for this might be that she was a third year student where Eric, Fred, and Grace were fourth year students. However, when specific leadership factors are self-assessed, students can identify the leaders even when the macro questions of "are you a leader" were not as indicative. Perhaps, then, students should be educated about the different traits of leadership so that they can identify when they are acting in a leader role.

In summary, from the interview, Eric showed clear indications of being a leader while Fred and Irene showed instances. Grace and Hank showed suggestions of progressing away from leadership responsibilities. In the questionnaire, Eric and Fred showed the most confidence and were the only ones to mark themselves as leaders in C2Q7. Irene showed lower values of confidence but was identified twice as often as others as being a leader in C2Q2. Further, Irene showed leadership in the evaluation sheet with the accuracy of her self-evaluation and scores of the averaged values.

CONCLUSIONS

Through these two pilot case studies, leadership has been clearly defined. Case Study 1 shows Carol and Dave as leaders throughout each of the data collection methods. Case Study 2 identifies Eric, Fred, and Irene as leaders of the group but there are discrepancies in the questionnaire and evaluation sheet. The questionnaire shows Irene as a leader, but Eric and Fred exude more confidence in their portrayal as leaders. Through these two case studies, the ethnographic study seems to be the most accurate and efficient method in Case Study 1 and the detailed interview was the most influential method in Case Study 2. A challenge with case study research is the repeatability and triangulation of self-assessment type of questions. Different styles of leadership have been found in the undergraduate design teams, without any formal leadership training being administered. Moreover, there was not, in either instance, a single leader that evolved from the teams.

Based on the challenges associated with this type of research, three data collection methods are recommended for use in future case study investigations:
1. Ethnographic Study: By the researcher immersing oneself in the environment of the capstone group, tallies of leadership traits will accurately show each individual's performance
2. Leadership Questionnaire: This method provides straightforward knowledge of leadership and confidence and is a better indicator of self-assessment than the surveys.
3. Detailed Interview: A detailed interview determines each individual's view of leadership, exposes specific situations which occurred, and clarifies aspects of the ethnographic study and questionnaire

Leadership in undergraduate engineering design teams is critical for the performance of each team. The wrong combination of students in a group can affect other qualities such as confidence, communication, and the project outcome. Once leadership is clearly identified within the group, then this leadership can be tracked. The students that were leaders in these projects can be monitored in other subsequent projects to determine if they roles and experiences of leadership evolve. The issue of gender and leadership within undergraduate design teams need to be investigated more fully. Other factors to explore include motivation and work climate due to leadership types.

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