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Engineering Design Team Leadership in Undergraduate Design Teams

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ENGINEERING DESIGN LEADERSHIP WITHIN UNDERGRADUATE DESIGN TEAMS

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ABSTRACT

The objective of this research is to develop an understanding of the emergence and distribution of leadership behaviors in engineering design teams. This research was conducted with undergraduate engineering students and explored leadership behaviors within design teams in a variety of contexts. Undergraduates were selected for the study since they possessed similar education and skills as a novice engineer in industry. A mixed methods approach incorporated qualitative and quantitative techniques including interview, case study, and protocol study instruments. The use of these methods enabled the exploration of leadership in both natural and controlled environments to capitalize on the research advantages of each.

Interviews were employed to understand faculty perceptions of leadership in design teams. The case study enabled the identification of leadership in a natural context without the need to control the multitude of variables in collaborative design. The protocol study provided a more focused and controlled study to identify patterns of leadership emergence and distribution of functions within a specific conceptual design activity: function modeling. The teams examined ranged from three to four-member design teams in the protocol study to ten-member teams with behavior resembling multiteam systems in the case studies.

The resulting insights provide increased understanding of the emergence of leadership and the distribution of leadership functions within design teams. Interviews manifested faculty perceptions that formal structures are developed early and that informal roles emerge throughout projects, with communication skills playing an important role.

Faculty perceptions on leadership covered a broad range of leadership functions including "performing task" and "consideration." The density of leadership networks during case studies confirmed the emergence of informal leadership functions among designers and indicated variations in function distribution at sampling points. Protocol studies indicated that informal leadership was established early, and that leaders active early remained active throughout these focused sessions. A single instance of variation in protocol study team size demonstrated a structural parity in a three-member team that was not observed in four-member teams. This supports faculty perception that larger and multi-dimensional teams also provided different opportunities for leadership development. This understanding will form the basis for further research into leadership of design teams and may assist in the development of leadership interventions in engineering design teams and design education.

DEDICATION

This is dedicated to my wife and my two sons. Thank you for all your support and patience through one career and into a new adventure. I'd also like to dedicate it to my parents for their many years of support.

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CHAPTER ONE: WHY UNDERSTAND LEADERSHIP IN ENGINEERING DESIGN TEAMS

1.1 Personal Motivation

Collaborative design and leadership within engineering design teams are recognized as critical elements of most engineering design endeavors [1–4]. As engineered systems become increasingly complex, the prevalence of design teams, and the size and degree of distribution of teams have also increased [5–7]. Only the simplest of designs can be accomplished without the benefit of a team, and in practice the design of a product may require multiple teams designing components and assemblies [5,8]. Leadership is a key contributor to the effective function of each of these teams and the products they design [2,9]. While the importance of leadership and management are well recognized, relatively little education and training is provided to prepare undergraduate students for their potential roles as project leaders [2,3].

As a military logistics manager, the researcher has experienced the challenges of leading multi-functional teams to fulfill logistic support requirements in distributed environments. While these products were primarily service oriented, this experience has motivated the researcher to obtain a greater understanding of leadership and communication within a variety of engineering team environments of varying organizational complexity. The importance of both formal and informal leadership and the value of shared mental models were a pervasive characteristic of these experiences. The research proposed here is designed to add to the body of knowledge of engineering leadership through the study of student design teams in capstone projects and controlled design experiments. It aims to increase knowledge of the impact of formal and informal leadership within these teams and to ultimately enable intervention techniques in student and industry design teams.

1.2 Dissertation Roadmap

This dissertation is organized as depicted in Figure 1-1. The introduction presented in Chapter One includes the overarching motivation for this research and an orientation to the dissertation. Chapter Two establishes the background by providing an overview of the literature relevant to engineering design team leadership. This background begins with an overview of collaborative design teams and a discussion of the classification of the collaborative design teams and their activities. It specifically addresses the classification of a collaborative activity that offers an environment for observation of design teams: design review meetings. It then addresses teams and multiteam systems as constructs for engineering design teams and leadership theory. Finally, a review of research related to engineering design team leadership is addressed.

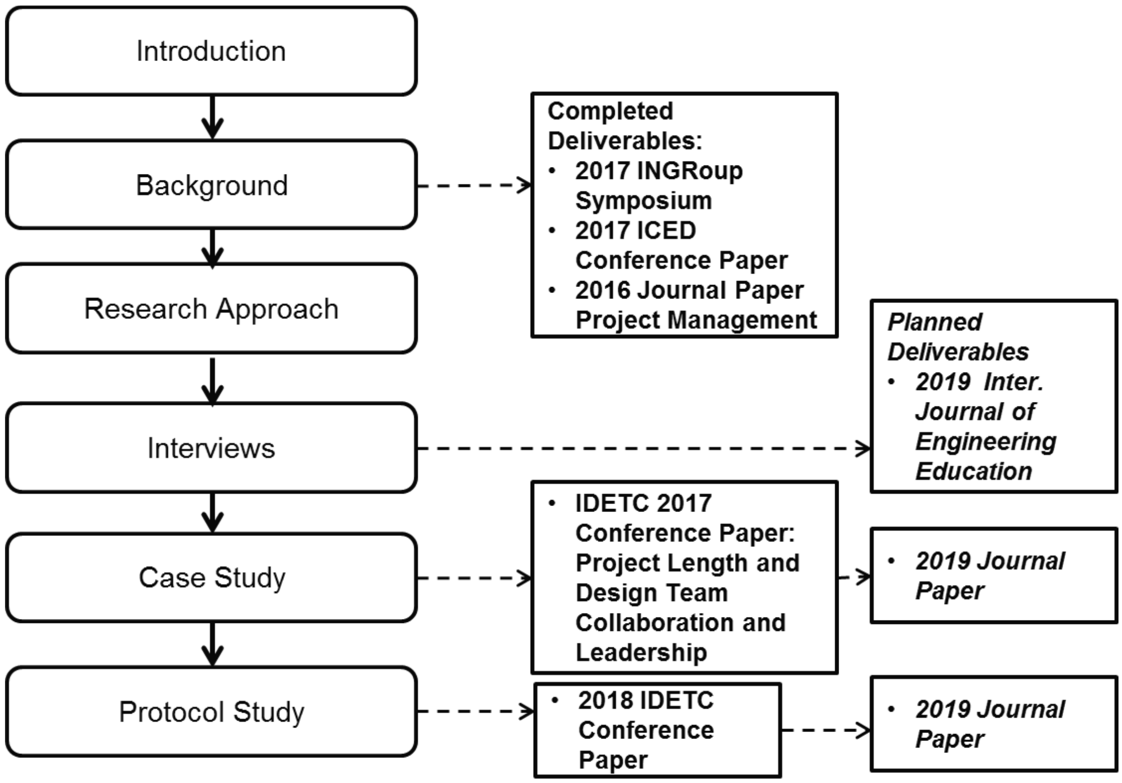


Figure 1-1. Dissertation Roadmap

Chapter Three is the overall approach to the research and its methods while chapters four through six detail the individual research methods that will be applied. The interview begins to develop and answer the research questions by seeking the perceptions of faculty on leadership and team composition. Chapter Four describes the development, progress, and proposed activities for the leadership interviews. Chapter Five outlines the leadership case study. This includes a preliminary study and its results and proposed work. The final chapter addresses the use of a protocol study to explore the emergence of leadership structures within undergraduate design teams creating function models for a novel design problem in the conceptual design phase.

CHAPTER TWO: CURRENT UNDERSTANDING ON ENGINEERING LEADERSHIP

2.1 Collaborative Design

Engineering design is the application of a systematic process and scientific analysis to develop an engineered product to fulfill needs or desires [5,8]. As a fundamental function of engineering, design relies on both physical and social sciences. The physical sciences such as material science, mechanics, and thermodynamics are needed to design a product that fulfills established specifications [5,10]. However, the physical sciences are not adequate to cover the full spectrum of design. Design includes people: both designers and customers. Social sciences describe the cognitive and collaborative processes of human designers [11]. These sciences also can help in understanding customer needs and designing machines that interface effectively with human users [12,13].

Design has been studied in diverse fields such as psychology [14], mechanical engineering [8], architecture [15], software design [16], and even military operations [17]. Engineering design generally requires the efforts of multiple individuals in teams to accomplish the goal of product realization, whether that product is a device, service, or both.

Collaborative design teams are teams of individuals working together to achieve shared design objectives. These teams require diverse compositions, processes, and approaches based on the nature of the problem and the team distribution. A taxonomy to facilitate characterization and modeling of collaborative design teams and their processes is found in [2,18]. The top-level structure of this taxonomy includes team composition, communication, distribution, design approach, information, and nature of the problem. This taxonomy is discussed in the next section.

2.2 Collaborative Design Taxonomy

A model of the collaborative design environment and its activities is a useful tool to understand the factors impacting these complex activities [18,19]. A taxonomy was developed to classify these teams and activities as a basis for further research [2,18]. The taxonomy is composed of the following six top level attributes: Team Composition, Communications, Distribution, Nature of the Problem, Information, and Design Approach. These attributes are then expanded to a detailed level of individual taxa that can be evaluated for specific design projects and teams. Three levels are defined for the classification scheme. The graphic of the taxonomy demonstrates some of the interactions between the individual taxa (Figure 2-1).

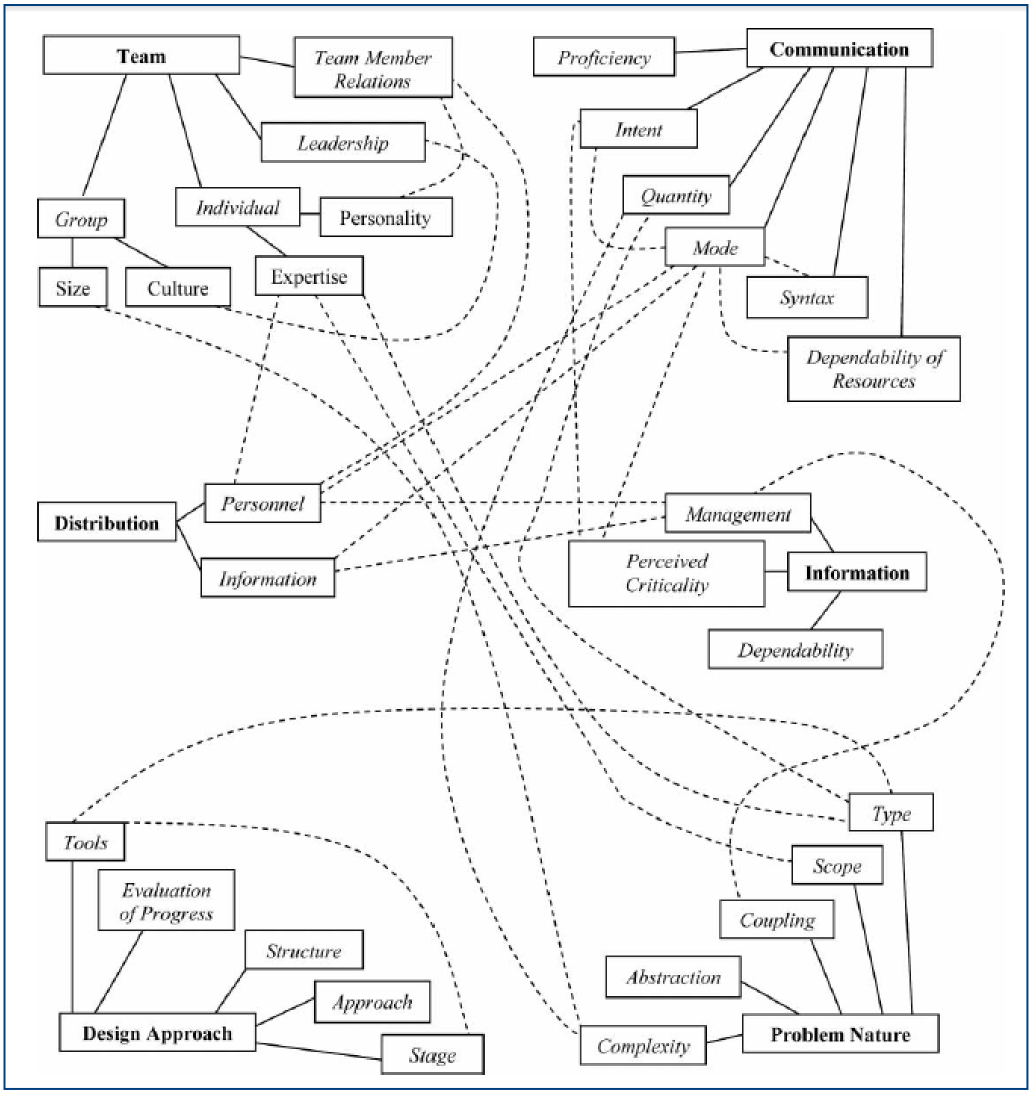


Figure 2-1. Collaborative design taxonomy [2,18]

The taxonomy was used to establish a model of collaborative design based on the metaphor of an electric circuit [20]. The theory has three basic concepts: passive knowledge, active knowledge, and circuit resistance. Passive knowledge, such as the engineer's experience or lessons learned on previous projects, is modelled as the voltage of the circuit. Active knowledge is considered the rate at which specific knowledge regarding the project grows. Specifically, active knowledge is an example of the rate at which the requirements documents grow, the generation of new function structures, or the evolution of prototypes. The growth of active knowledge acts as the systems' electrical current. Finally, the resistance of the circuit is modelled by the taxa of the collaborative design taxonomy. The top tier taxa are described below.

2.2.1 Team Composition

Team composition describes the make-up of the team as defined by the characteristics of the group, its individual members, the relationships of its members, and the leadership within the team. These characteristics represent the second tier of the taxonomy within team composition. Various aspects of team composition have been the subject of engineering design research and further research is ongoing [21–25]. Leadership is a subordinate taxon to team composition. Leadership will be further discussed in section 2.5.

2.2.2 Communication

Communication is described in the taxonomy by its mode, quantity, intent and syntax. It is also categorized by the team’s communications proficiency and the dependability of available resources. Communication is central to collaborative design processes since it is the means by which information is conveyed [18]. The information is shared and compiled allowing the team to synthesize knowledge and facilitate concept and solution generation. It is also hypothesized to impact creativity as long as it is not excessive or distracting [26]. Research also suggests that communication and communication structures are closely linked to leadership behaviors and structures [27].

2.2.3 Distribution

Distribution refers to the geographic, temporal, or organizational separation of team members or information. Distribution impacts the means and potentially the effectiveness of communications in design teams [28]. The distribution of team members and information creates new challenges and requirements for these teams [26].

2.2.4 Design Approach

The design approach includes the design team's approach to the problem and the means by which the team's progress is evaluated. The second tier of the design approach includes: design tools, evaluation of progress, degree of structure, process approach, and stage [2,18]. The stage is the current position of the team in the systematic design process [5,8]. While the taxonomy uses the mechanical design construct, it could also be represented by alternative approaches such as the systems design process [29–31].

2.2.5 Information

Information is subdivided into information management, information criticality, and information dependability. The ownership and sharing of information within the team can impact the effectiveness of design activities [32] while the accumulation and refinement of information is central to the design process [33].

2.2.6 Nature of the Problem

The nature of the design problem itself will also impact the design team and its activities. This is characterized in the taxonomy by its type or novelty [8], how tightly it is coupled, the degree of abstraction [34], the scope of the problem, and its complexity [35].

2.2.7 Summary

The collaborative design taxonomy provides a framework to understand collaborative design teams and activities. It also provides a reference to identify the primary variables involved in design research. In this way, it assists with identifying variables that should be controlled or measured for a given design study.

Leadership is a taxon within the team composition category and is identified as interacting with the team's culture, although there are additional interactions with taxa such as communication, information and design approach. When designing collaborative design experiments, it is useful to consider the taxonomic factors as they are related to design teams and activities involved in the study.

The taxonomy as depicted in Figure 2-1 identifies a linkage between leadership and culture. A review of the literature identifies multiple interactions between leadership and other taxa. Since leadership involves influence, these interactions should be expected. Leadership is strongly linked to communication [27,36]. At least one author has described it as an activity anchored in communication [36]. Information control and management have been tied to leadership emergence [37]. Leadership techniques may need to be modified in distributed environments and guidelines have been suggested for leadership in distributed environments [38,39]. Contingency models have included the degree of a problem's structure as a factor in leadership approach [40] as leaders have influence over the approach to the problem. The extent of possible interactions suggests that leadership has a high degree of centrality to taxa within a collaborative environment.

2.3 Design Review Meetings

A common feature of collaborative design processes is the design review meeting. Design review meetings are coordinated or collaborative activities conducted to evaluate design progress or artifacts and to aid in the decision making process regarding the design [3,8,12,31,41]. Design reviews are in many ways a microcosm of the design process, and provide insights into the collaborative design process, either on a recurring basis or at major project milestones. The current categorizations of design reviews reflect the multi-disciplined nature of design [42]. Design reviews are categorized within individual disciplines and organizations; however, there is not a current and comprehensive taxonomy of design reviews or design review meetings. The approach for this review encompasses a survey of research and foundational texts from mechanical engineering, systems engineering, systems engineering, psychology, and management. The literature is surveyed to establish current categorizations of technical design review meetings and to characterize the major components of the design review environment. This review also summarizes current and ongoing research activities relevant to the topic.

2.3.1 Classification framework

The framework for a classification of design reviews, and their characteristic environment and activities is presented based on a review of the literature relevant to engineering design reviews. The framework is summarized and depicted in Figure 2-2. The bottom half of Figure 2-2 represents the classification of design review meetings; or stated in another way, the different types of design reviews. The top half of the diagram represents the different aspects of the design review environment and its component activities.

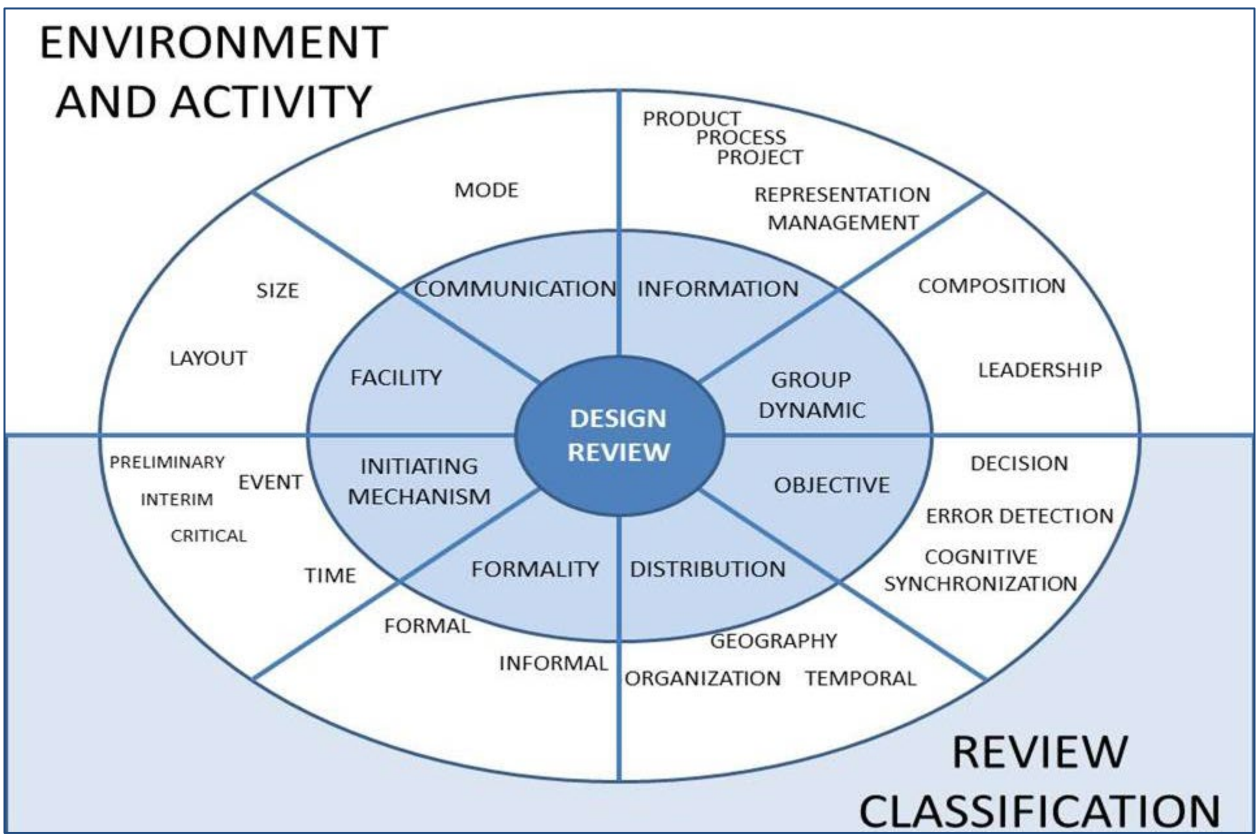


Figure 2-2. Design review classification framework [43]

The components of the figure are hierarchical. With the design review itself in the center, the first concentric circle out from the center represents the first order of the hierarchy. It is divided into eight distinct categories: four describing review types and the remainder identifying review environmental components. This first level of specificity for review classifications consists of initiating mechanism, formality, distribution, and objective. The first level of environmental components consists of facility, communication, information, and group dynamic.

Remaining levels of decomposition are depicted within the largest concentric circle (white background). The second level of decomposition is closest to the interior of the sector, with the third level closest to the exterior (as required). For example, initiating mechanism is one of the means of classifying reviews (first order). Initiating mechanism may be divided into event and time driven reviews. Event driven reviews may further be subdivided into preliminary, interim, and critical reviews.

2.3.2 Categories of Engineering Design Review Meetings

There is not a comprehensive categorization or taxonomy of design review or technical review meetings. There are related taxonomies that are instructive to efforts to categorize design reviews. A taxonomy of collaborative design activities was developed that is instructive due to the collaborative and team oriented nature of design reviews [2]. There are also categorizations provided within specific texts and research papers that are useful in understanding design reviews. Based on the research, a framework for categorization of design reviews as related to multi-disciplinary, concurrent or collaborative design is provided. Design review meetings may be categorized by their initiating function or purpose, who participates, degree of distribution, synchronization, and formality (Table 2-1).

Table 2-1. Design review literature review

Category	Reference
Initiating Mechanism	[8,29,31,42,44]
Formality	[44–46]
Distribution	[12,47–49]
Objective	[50,51]

2.3.2.1 Event or Time Initiated Reviews

There does not appear to be a common, standardized construct for the timing of design review meetings [42]. Due to the range of corporate, governmental, non-governmental organizations conducting design reviews, it is not plausible that there will be a standardized, "one-size fits all" template for design meetings. However, design reviews may be categorized by their initiating function. This function will determine when design review meetings occur, or at least how these meeting times will be determined. The primary means used to specify this function are event driven reviews and time driven reviews [8]. Event driven reviews are conducted at specified project milestones or to review specific design artifacts. These review meetings are predominant in systems engineering texts and references. Time driven meetings are scheduled at predetermined frequencies such as weekly, quarterly, and annually.

Design reviews may only be appropriately conducted in conjunction with completed milestones or design artifacts. In this way, they are used to control iterations of the design process [42]. The NASA Systems Engineering Handbook provides defined milestones for the primary engineering reviews within National Aeronautics and Space Administration (NASA) projects [29].

The primary engineering reviews conducted within NASA projects, as prescribed in the handbook, are Preliminary Design Reviews (PDRs), and Critical Design Reviews (CDRs). Additional reviews conducted throughout the lifecycle of the design are the Requirements Review and the Acceptance Review. Each of these reviews is conducted in close temporal proximity to a designated key decision point, or KDP. The PDR is conducted to evaluate the preliminary design and to ensure that it will meet the project requirements and is projected to meet programmatic restraints such as program budget and timeline [29]. The critical design review is conducted to evaluate the design and verify that it is ready for construction and assembly. This is conducted at a much later stage in the design. There are detailed checklists provided for each of these reviews that specify the inputs and outputs of these meetings. In addition to these two primary design reviews, there are several (system definition, system requirements, system integration, and system acceptance) additional systems level reviews that are provided on the project timeline.

Systems engineering reviews can classify these milestone driven reviews as conceptual design, system, critical, and equipment design reviews. The conceptual design review evaluates the conceptual system design to include the maintenance concept and the requirements analysis. System reviews are convened to review system characteristics such as lifecycle planning, personnel and maintenance requirements, budgeting, and reliability. These topics correspond to those addressed in the six individual systems meeting in the preceding paragraph. The equipment reviews are conducted to evaluate specific technical artifacts or technical reports. The critical review corresponds to the same critical design review in the NASA handbook and comes at the conclusion of the detail design [31].

Although most design reviews in the literature are event triggered, review meetings do occur based on routine scheduling [52]. This appears to be the case both for engineering students and in industry [53]. Concurrent engineering provides an environment with multiple concurrent efforts that often require synchronization and collaboration. A mathematical model to explore the optimal timing of concurrent design reviews incorporated predicted time savings due to timely decisions and also penalties due to preparation time and re-work resulting from design refinements and iterations [54]. It predicted that process dominated projects (possibly mature designs) would require early reviews with decreasing regularity as the product matures, while product intensive projects may require an increasing meeting tempo as the project progresses. It also explored the tradeoffs between the preparation time lost preparing for meetings and the benefits of timely decision making. The model may provide some insights into design review timing, however, it is based purely on a simplistic model and not on an industry case study [54]. Significant research would still need to be conducted to substantiate the usefulness of the model based on industry or engineering student design team data.

2.3.2.2 Formal and Informal Reviews

Design reviews may be categorized as formal or informal reviews and are performed and identified in these terms in many technical fields. Formal review meetings are scheduled, have defined inputs and outputs, mandatory membership, structured process, and specified documentation. These meetings are prescribed; however, they may take many different forms such as "walkthroughs, inspections, and review meetings [45]." The Project Management Body of Knowledge Guide correlates these inspections to "product reviews, audits and walkthroughs" [46].

Informal reviews are reviews that are generally conducted without the prescriptive boundaries and procedures that characterize their more formal counterparts. They may be conducted in person or via electronic media. They may also be conducted synchronously or asynchronously and the study of informal communication in design reviews has been identified as a research need [45]. Peer reviews are generally conducted to prepare for formal review mechanisms and may involve both designers and management personnel. These reviews should have sufficient focus and structure to maintain productivity and efficiency, while retaining sufficient flexibility and freedom for participants [44].

2.3.2.3 Peer Reviews

Peer design reviews are meetings or activities in which the active participants are peers and the primary activity is the evaluation of design progress or design artifacts. These meetings are held in several technical disciplines, although their composition and conduct can be dissimilar. Research has been conducted on peer review meetings in the engineering and software fields to recommend improvements to the peer review process. Peer reviews are binned as both formal and informal meetings by the authors surveyed. It appears that both formal and informal reviews may be conducted depending on the culture and processes of the organization in consideration. In either case, the meetings still have a specified but flexible function; and, documented outputs [44,45].

Peer reviews have been studied via protocol study within the context of software engineering. These meetings did not include corporate management or leaders from outside of the design team. The research team assigned specific roles (project supervisor, author, and reviewer) to participants in the reviews to evaluate the influence of these roles on participation. The authors concluded that assigned roles had a large influence on the participation of the individual members. They also recommended that peer reviews should include the project supervisor due to his decision-making authority and influence on project management. Finally, they propose a hierarchical approach to peer reviews. In this approach, reviews would be tiered into three levels including form review, cognitive synchronization, and defect detection [45].

Traditionally each of these functions is performed during a collocated and synchronous review meeting. The form review is a quick review of the artifact or document and does not require significant discussion. The authors assert that the form review could possibly be executed by a single individual in the role of reviewer. This approach enables the design team to maximize effective participation in the review, while, minimizing wasted labor cost. The cognitive synchronization is held to increase the awareness of the team and to foster a common understanding and vision of the artifact under review. The second event would include the largest participation of the three reviews and could include stakeholders outside of the project team. The final event would be the actual defect recognition meeting. This meeting must include the author of the item and the project supervisor [45].

“Peers” at NASA are typically assigned from outside of the design team according to the authors. A case study of the NASA peer reviews describes these meetings as precursors to the formal meetings that include the preliminary design review and the critical design review discussed previously. The significance of using peer review checklists and documenting the contents and results of the meetings is emphasized. Managers are not included in these peer review meetings [44].

2.3.2.4 Distributed Design Reviews

Design reviews will reflect the nature of the design team project and the composition of the design team. As design teams are increasingly distributed as a result of globalization, design meetings will also distribute. Design review meetings may be distributed geographically or temporally. In the first case, teams will be separated by geographic distance making it often impractical for design reviews to be held in a traditional face-to-face context. Meetings may be facilitated by technological means [2]. While the challenges associated with distributed environments may seem relatively intuitive, the distribution caused by organization boundaries can be equally inhibiting.

Collaborative design in geographically dispersed environments has been studied [47]. In one study, the researchers created a design team of multi-disciplinary students spread across four universities. They held weekly synchronous design reviews with the assistance of video teleconferencing, e-mail, and solid modeling software. The researchers evaluated the interactions of the design team during the meetings to quantify the interactions of the team members as design activities, relational activities, or interaction management. They found that design activities were predominant in collocated and distributed meetings. However, they also found that interaction management increased in significance in distributed meetings. The project manager was required to actively manage interactions that occur more naturally than in face-to-face meetings. For example, the manager had to control "taking turns" speaking, screen usage and other media synchronization. The loss of visual cues and behavioral context increased the work load required to manage these interactions [47].

Between distributed but synchronous design reviews, the teams were required to collaborate in an asynchronous manner. However, these asynchronous activities were not strictly review activities. The team members tended to focus on building and refining three dimensional models during this time. Information was primarily exchanged via edits to models (in Solid Works) or by e-mail. There is a remaining gap in research and evaluation of asynchronous engineering design activities.

Others have surveyed collaborative environments for distributed, concurrent engineering design [48]. They indicate that multi-disciplinary, concurrent design teams will encounter challenges with team building and interaction. From their survey of concurrent design environments in industry, government, and academia, they develop a brief taxonomy of the concurrent design environment. The majority of the environments surveyed were focused on the aerospace industry. They identify software, hardware, and the interactions of people with other people and systems as the critical components of any concurrent and distributed design environment [48].

In the field of software design, reviews are conducted in order to identify and correct code errors and to evaluate system architectures [12]. The architecture reviews correspond with system reviews discussed previously. One study focused on the feasibility of conducting software technical reviews without holding synchronous, face-to-face meeting [49]. Their intent was to evaluate the effectiveness of replacing face-to-face meetings with concatenated individual reviews [49]. The researchers conducted an experiment consisting of code reviews of the same code using different methods. One group of participants conducted traditional, collaborative review meetings. The second group conducted individual reviews that were then collected and merged. The research did not show any clear connection between the quality of the error detection and the method used by the two groups. In other words, the costlier design reviews did not result in more errors being detected. However, the group reviews produced fewer errant results, or false positives. The participants of the group reviews were also more confident in the result of their reviews, although the group's results were similar. This confidence may result from their awareness of all of the group's results and the awareness built by their participation in the review [49]. These results could indicate that asynchronous reviews may be equally effective as time consuming meetings in certain circumstances. However, they also demonstrate that there are other possible benefits of the group activity. The information that was only shared between individuals and project leadership did not build the knowledge of the group. If specific design reviews are eliminated, care should be taken to understand the implications of this reduced knowledge and awareness of the design team.

Additional research is needed to verify this result. This result could also be verified in a different functional domain such as mechanical engineering. There does not appear to be a set of guidelines or a significant body of research on the efficacy or conduct of asynchronous design reviews. If the efficacy of these asynchronous reviews is verified, additional research should be conducted to establish guidelines for their applicability to specific review activities.

2.3.2.5 Decision or Cognitive Synchronization

Design reviews have an evaluation or error detection function by definition. This implies that the evaluation will either conclude with or precede a decision-making function. Design reviews are often the place "where key decisions and their rationale are made explicit" [50].

Organizational design decision making has been described in terms of the Observe-Orient-Decide-Act Loop detailed by John Boyd [55]. The process of design decision making is iterative, and design reviews as decision points are a key gateway to iterative loops. Organizations and teams often are challenged to make decisions, delaying the design process and resulting in excess costs [56]. The design review serves at least two of the major components of the decision cycle: orient and decide.

The meeting often assists with orienting leadership to the design problem and progress towards meeting its requirements, or it may assist in providing a common vision or orientation to the design team itself. The interactional approach considers the argumentation and how the designers participate in the design process. The functional approach specifically addresses the actual actions that occur in the design meeting. The authors bin these activities as cognitive synchronization, technical review, elaboration, conflict resolution, and management. Although the explicit definition of a design review is one of evaluation, or review, most of the time in design reviews is devoted to cognitive synchronization. In their study, 41% of the exchanges between meeting participants principally involved this function [51].

Cognitive synchronization activities were defined as those involving the common viewpoint of the group in terms of the design or design alternatives. This also results in the solutions to problems, new requirements, or requests for additional information. In essence, these interchanges increase the awareness and shared vision of the group and can result in creative activity [51].

2.3.3 Team and Collaborative Environment

The team composition and its collaborative environment are derived from the collaborative design taxonomy and its intersection with design review research. Communication, information, and group dynamic are retained from the collaborative taxonomy. One aspect of the environment that is an addition as an aspect of the environment is the facility in which the meeting is conducted. The collaborative environment is consistent with the definition of environment provided for the concurrent engineering environment (CEE) in a previous study. This environment was defined as any physical or virtual environment that facilitates concurrent engineering [48,57]. As such, it includes the mode of communication in addition to the facility. The collaborative environment is inclusive of the CEE but is broader to include collaborative design team environments that might not be strictly defined as concurrent design teams.

2.3.3.1 Group Composition

The review is typically conducted by a group of members, sometimes of diverse skills and backgrounds. The size of the group is one feature of the group composition [2,3]. There is no apparent literature on the appropriate size of membership of a design review specifically. Research results generally report the size of the group utilized in the study or in a particular design review, but do not appear to evaluate the optimal size range for a particular design review or provide guidelines for determining group size. In a review of research on multi-team systems, Shuffler reports that research results are not conclusive on the size of teams and number of teams in a multi-team system [58]. A multi-team system lens could be used to study design teams of complex systems.

Another division of group composition is the group's culture. A questionnaire was developed for the evaluation of team behaviors and their impact on group dynamics. The questionnaire was based on interviews with design professionals in mechanical engineering, chemical engineering, information, communications, and architecture [59]. Although the questionnaire was not specifically developed or evaluated for the study of design reviews; the questionnaire could be applied to future research on design reviews.

2.3.3.2 Communication

The impact of communication mode on design reviews has been evaluated in a user study by presenting student mechanical engineering design groups with the task of reviewing design artifacts for errors. One subset of the participants conducted the reviews in collocated, or face-to-face, meetings. The second subset was placed in separate rooms with varying communication tool sets to simulate a distributed environment. The study determined that the participants had a higher degree of confidence in their reviews when the reviews were conducted face-to-face, regardless of whether or not the results were actually more accurate [3].

This is complemented by research conducted by research in the field of software engineering. One group of reviewers conducted a review of code in a traditional group review meeting. The second group conducted the reviews asynchronously. While the results of both techniques yielded equivalent effectiveness in identifying errors, the participants preferred the traditional method and held a higher degree of confidence in the results. The authors hypothesize that one reason for the false-confidence could be related to the communication and shared awareness that occurred in the group review [49].

2.3.3.3 Information

Information management is a key activity within the context of design reviews [2]. Information is a central function of review preparation, sharing of information among review members, documentation of decisions and annotations. Three tools have been developed to capture the contents of aerospace design reviews. The first tool, the transcript coding scheme (TCS) utilizes true meeting transcripts. The transcripts are coded by their contents. This method is time consuming but provides very detailed and complete recording of the meeting's information content. The second tool is the meeting capture template (MCT). This is a template that can be filled in by a knowledgeable observer. The information is not as detailed and complete, but, it is less time-consuming and does not require the formal training of a rapporteur or full recording of the meeting. This can be performed as a more thorough means for practitioners to capture meeting contents in addition to its use in research. The third tool is the information mapping tool, or MCT. This tool is designed to capture the information that is typically lost in meeting minutes by mapping, or tracing, the information. In essence, it enables the comparison of the official meeting minutes to the actual information contents of the meeting. Within their research, they also offer classification of the information controls in design reviews: confidentiality, control documents, synchronicity, and organizational standards. [60]

2.3.3.4 Facility

The physical facility of a design review is an element of the design review. Room set-up and furniture layout impact the conduct of meetings and the accomplishment of other routine tasks [61]. Although facilities are not listed in the collaborative design taxonomy, they are a natural addition to the environment classification of design review meetings.

2.3.4 Summary

Design review meetings provide a microcosm of the design process and serve as an opportunity to observe design team behaviors. These design activities provide an opportunity to observe collaborative team behaviors to include leadership behaviors. A framework for design review meetings serves as a means to classify these meetings and to understand the environmental and team factors influencing them and their outputs. These meetings have been used as the environment for previous case study research. This research identified transformational and transactional leadership within design review meetings of undergraduate Capstone design teams [62].

2.4 Teams and Multiteam Systems

A team is defined as an interdependent group of individuals performing a common task or tasks. The team often exists within the context of a larger organization or group of organizations. The common task and interdependence distinguish the team from a simple group [63]. The formation of teams enables an organization to combine individuals with multiple areas of functional areas of expertise to solve a common problem. Teams also allow interaction between multiple social perspectives and insights. Design teams are commonly formed to complete designs or accomplish design tasks [63].

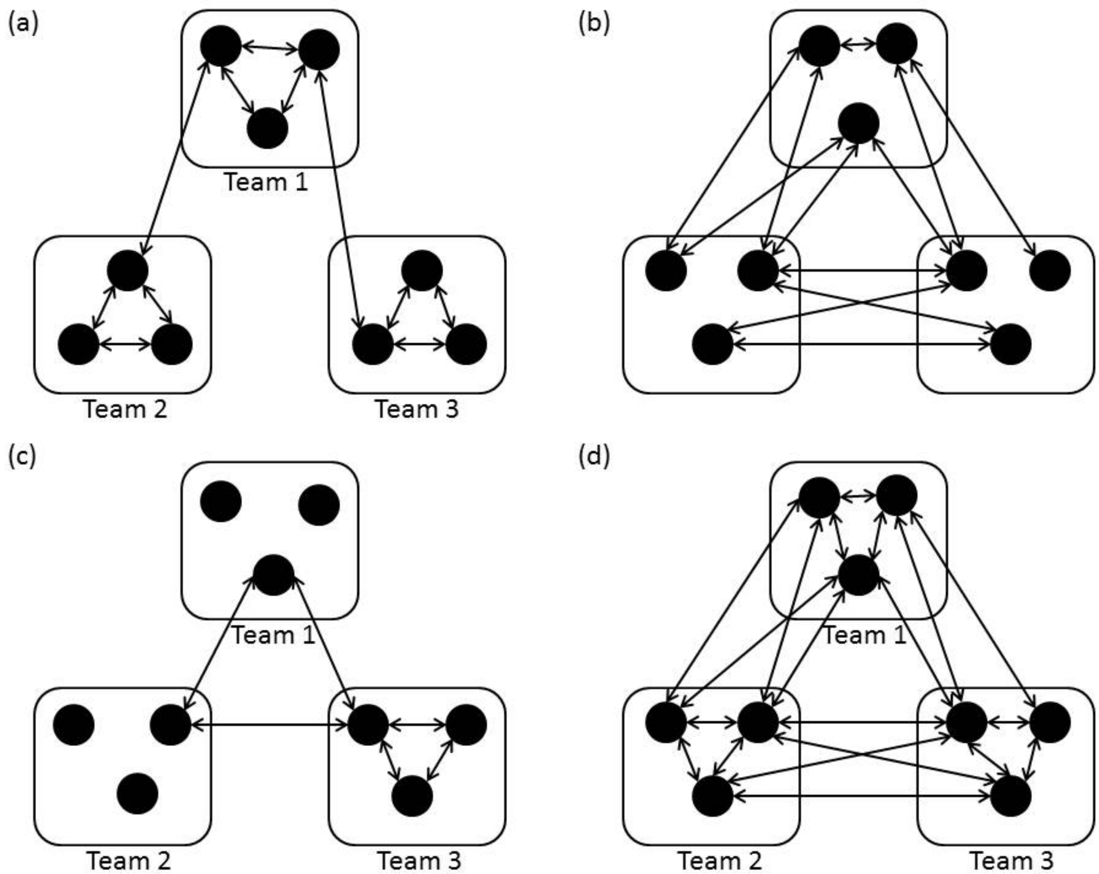


Figure 2-3. Representative leadership densities in multiteam systems adapted from [64]**: (a) leadership density within teams, (b) density between teams, (c) density within one team and between teams, (d) density within and between teams**

While teams may function independently, they may also serve within systems of teams. This system of teams is considered a multiteam system (MTS) when there is more than one interdependent team working to achieve a common goal. This relationship can exist within engineering constructs of complex products or in concurrent engineering. In an MTS, the interactions and relationships between component teams often share equal significance with the collaboration within component teams [58]. Team members may also be members of multiple teams within the multiteam system [65]. Representative leadership network structures are depicted in Figure 2-3. In Figure 2-3(a), leadership density is prevalent within the system's component teams. In Figure 2-3(b), leadership density is between teams spanning the system's boundaries. The third representation, Figure 2-3(c) is a mixture of dense inter-team interactions and one team with dense internal interactions. Finally, the fourth representation of Figure 2-3(d) includes a fully dense MTS.

2.5 Leadership [66]

Leadership is of interest in a variety of fields including psychology, management, military studies, athletics, and engineering [15,67–72]. It is also defined in a multitude of ways. As one author states: "…there are as many definitions of leadership as there are people who write and speak about it" [73]. Leadership can be defined as a group of leaders, characteristics of leaders, or tasks performed by leaders. For this research, "leadership is both a process and a property. The process of leadership is the use of non-coercive influence to direct and coordinate the activities of the members of an organized group toward the accomplishment of group objectives. As a property, leadership is the set of qualities or characteristics attributed to those who are perceived to successfully employ such influence" [74].

2.5.1 Leadership Theory

Leadership models have been proposed as early as 2000 years ago [37,75], however, authors argue that modern leadership theory development can be traced to the mid nineteenth century [36,37,76]. Early theories assumed that leadership was a characteristic endowed in individuals at birth. Later theories espouse the idea that leadership can be developed and examined through various lenses including behavioral and interactional. The following subsections and Table 2-2 provide a brief overview of selected leadership theories and their evolution.

Table 2-2. Leadership theory overview

Theory	Reference	Contribution
Trait	[36,37]	Explored connection of personal characteristics to leadership
Behavioral	[37,77]	Established primary categories or factors of leadership behaviors
Contingent	[36,40,78,79]	Leadership behaviors are not equally effective in different situations
Functional	[80–83]	Established specific functions for leadership Study leadership vice leaders
Leader-Member Exchange	[36,71,84,85]	Leadership activity is a relationship between leader and follower/member
Transformational Transactional	[70,86,87]	Explores charismatic leadership

2.5.1.1 Trait Leadership

Trait theories dominated writings on leadership until the 1940's. Trait proponents theorize that leadership is the result of characteristics or traits possessed by the leader [36,37]. These characteristics have ranged from physical characteristics such as height and attractiveness to personality and character traits such as integrity and forcefulness [37,88]. A milestone review of the literature in 1948 reviewed 124 studies of leadership traits and characteristics. Many of these studies provided contradictory results. For example, six studies found that leaders were generally younger, while ten concluded that leaders were generally older. Two were unable to find a correlation; finally, one determined that it is situationally dependent [88].

The large variance in trait study results is problematic and has been used by theorists and researchers to discredit any relationship between traits and leadership. However the author does not conclude that traits are not a component of leadership, just that they are not the sole factor and that their impact is situational in some cases [36,37]. The factors that are identified as "associated" with leadership include: capacity, achievement, responsibility, participation, status, and situation. These factors can influence the emergence, assignment and performance of leaders in a given situation [36,37,88]. Some recent studies find that relevant characteristics such as cognitive ability may be clearly related to leadership, but are not sufficient to predict or guarantee emergence or success [89].

2.5.1.2 Behavioral Leadership

Behavioral leadership theories emerged in the late 1940s [37]. As the title suggests, these theories focus on the behavior of the leader rather than personal characteristics. The principal behavioral leadership studies were conducted at Ohio State University and the University of Michigan in the 1950's [90]. Researchers listed behaviors and grouped them into two primary behavior forms: initiating structure and consideration. Structure is the propensity of the leader to organize roles and tasks to achieve goals. Consideration is the tendency of the leader to develop relations and establish trust with team members [37,91]. The Michigan studies researched behaviors categorized as job-centered and employee-centered [77]. Both research groups developed questionnaires that asked subordinates, or sometimes peers, to evaluate leaders according to these characteristics [37,77,92]. While different, the two constructs have clear parallels. Leader behaviors are grouped according to an orientation on task and an orientation on relationship. Behavioral researchers expanded leadership theory beyond pure traits to one that focused on leader behaviors. This enabled new methods of research by case study and observation. The primary proponent of the Ohio State studies concluded that leadership is impacted by both behavior and traits [90,92].

2.5.1.3 Contingent Leadership

Contingent, or situational, models theorize that leadership style should be different in the variety of situations or episodes a leader will face [36]. Specific theories characterize these situations by factors such as employee maturity, the nature of the problem, or the importance of acceptance by team members. The combination of characteristics presented in a situation then drive the choice of the degree of participation of members in the solution of the problem or the decision making process [40].

2.5.1.4 Leader-Member Exchange

Contingent leader theories acknowledge that leadership styles may need to vary depending on the team's environment. Leader-member exchange theories develop the concept that leaders do not treat all members of the team in the same manner. For example, a leader may share a higher level of trust with one team member than another and may offer a higher level of responsibility. Relationships between leaders and members are treated as dyadic relationships. A member may be characterized as a stranger, an acquaintance, or a partner based on the level of shared task and relational trust [36]. The contribution for the purposes of this study is establishing the significance of studying the "exchanges" between leaders and members.

2.5.1.5 Transformational and Transactional Leadership

Transactional and transactional leadership theories were developed starting in the 1970s [76]. Transactional leadership involves establishing goals and rewarding their achievement. Transformational leadership focuses on intrinsic motivation sources. The leader motivates change through charismatic action, intellectual challenge, and consideration [36,86]. Transformational theory attempts to establish that this form of leadership is more effective, particularly in changing organizations [76].

2.5.2 Functional Leadership

Functional leadership builds on the concepts introduced in behavioral theory. Behavioral theories identify categories of leadership behaviors. However, behavioral theory proposes patterns of behavior that a leader should exhibit, such as structure and consideration. Functional theory extends to the identification of leadership processes, or the functions that leaders fulfill [36]. Leadership functions are behaviors or roles that leaders perform. Leader functions have been identified as task and group building (relational) [36]. These functions are not equivalent to functions described as transformative actions in the engineering design process [5,8].

The functional approach to leadership is the most commonly applied framework for team research and provides a taxonomic approach to the observation of specific leader behaviors within teams [82,83,93]. It identifies actions that leaders take to affect the success of their team, such as coordinating, motivating, synthesizing information, communicating, and providing resources. These processes in turn impact the teams cognitive, motivational, affective and coordination processes in an effort to achieve team success [82].

2.5.2.1 Temporal Construct

Engineering design occurs within a temporal construct that includes project deadlines and milestones. Design teams establish schedules and routines to synchronize their activities with these timelines [29–31,43]. A temporal model for team processes has been developed and applied within the context of team research in industrial organizational psychology [81,93]. This temporal construct has also been applied to leadership functions as a subset of team processes [82,83]. This model describes team activities as a recurring series of transition and action phases. Transition activities generally involve assessing previous actions and preparing for future actions. Action activities are directly related to the team's task work.

These functions have been ascribed to action and transition phases [83]. The transition phase includes activities such as vision setting and developing strategies while the action phase includes monitoring and guiding progress, coordinating lines of effort, and assisting team members with tasks. The source taxonomy of leadership functions ascribes relational functions to the action phase [83]. However, relational activities such as conflict resolution and encouragement occur within both the transition and action phases [81,93]. The framework proposed for this research utilizes this framework of relational activities occurring across phases as espoused in the taxonomy of team processes used in the formulation of the leadership function taxonomy [81,83]. These functions will be utilized to form the basis of observational coding protocols for this research and are summarized in Table 2-3.

Table 2-3. Leadership functions adapted from [81,83]

Phase	Function
Transition	Compose team
	Define mission
	Establish expectations and goals
	Structure and plan
	Train and develop team
	Sense making
	Provide feedback
Action	Monitor and Guide
	Manage team boundaries
	Challenge team
	Perform team task
	Solve problems
	Provide resources
	Encourage team self-management
Relational	Support social climate
	Consideration
	Empowerment

2.5.2.2 Transition Functions

The seven transition phase functions are described below.

- Compose team. Team composition has been previously discussed as a characteristic of the design team in 2.2.1. The compose function consists of selecting team members in order to ensure that the team possesses the necessary skills, technical and interpersonal, to accomplish its mission. This includes adapting the team to environmental changes [83].
- Define mission. This function entails establishing the team's purpose and objective. It also includes ensuring that all team members have a common understanding of the mission and that it is aligned with external

requirements [81,83]. On a design team, this could include external leadership expectations and customer expectations.

- Establish expectations and goals. Goals are established for team members and overall team performance. The leadership structure will impact the shape of this function. For example, a formally appointed leader may be more directive [83].
- Structure and plan. Organizing work in a structured, coherent, and logical fashion for the team is a function that impacts team performance. Representative outputs of this function for a project team may include products or input to products such as Gantt charts and work break down schedules [46]. This activity is prominent in the planning and task clarification stage of the design process, but occurs iteratively with changes in the design environment [5,8].
- Train and develop team. Leaders develop or provide training to team members to improve their performance of the team task. This includes training on technical expertise and team work.
- Sense making. Acquiring information from inside and outside of the team, translating into meaningful knowledge, and conveying that to the team is central to leadership [82]. This function is known as sense making and has been demonstrated to contribute to creation of shared mental models for the team [83].
- Provide feedback. Feedback enables a team to respond to changing conditions and improve performance. Feedback on short-term tasks is often provided by informal leaders while long-term performance is commonly evaluated by formally appointed leaders.

2.5.2.3 Action Functions

The seven action phase functions are as follows:

- Monitor team. Observing and evaluating team performance and progress is referred to as monitoring the team. This includes observing team members individually, observing changing conditions in the environment (design problem), and team resources. Monitoring is distinguished from providing feedback in that feedback is an input to feedback that is then provided to the team. Monitoring may also act as a "sensor" function that actuates other action or transition phase functions [83].
- Manage team boundaries. Boundary management involves the establishment of boundaries and managing interfaces with teams and individuals outside of the team. An objective of this function is to optimize the competing goals of situational awareness and integration with a larger system, and reducing unnecessary disruption and interference [83].
- Challenge team. Challenging team members or the team as a whole to re-evaluate its norms, procedures, and performance can improve team function and outputs [83]. Challenging the team can mediate improved performance by changing team processes [82].
- Perform team task. A leader performing the team task could be described as "getting their hands dirty." This function could manifest as an external leader helping perform task work for the team. Or it could be one team member working beyond his own personal responsibilities to help teammates [83].
- Solve problems. A leader may solve problems for the team. This can involve facilitating and combining the contributions of multiple team members; or applying the information and technical skill to generate solutions for the team.
- Provide resources. Engineering design teams require fiscal, human, supply, and information resources to complete their tasks. The leader works to identify, obtain, and allocate these resources for the team.

- Encourage team self-management. Encouraging self-management is generally performed by an external, formally appointed leader. This may serve to reduce the leader's task saturation allowing him to dedicate attention and time to other leadership functions. It may also improve member satisfaction and efficacy [83].

2.5.2.4 Relational Functions

The three relational phase functions are performed during both phases and are defined below:

- Support social climate. Interpersonal processes may be influenced by formal or informal leaders. Activities such as respecting and encouraging member ideas, showing concern for personal welfare, and relating to team members may serve to support the social climate of the team [83].
- Consideration. Consideration is the process of respecting members of the team and ensuring they may participate in the teams processes and tasks [94].
- Empowerment. Empowerment is the process of strengthening the confidence of team members in their own abilities. It involves activities such as encouragement and support, in addition to allowing members to develop skills [94].

2.5.3 Leadership Structure

Leadership function performance is not restricted to formally identified leaders [83]. Leadership may be exercised by those holding formal leadership positions and authorities, or informally by agents without defined leadership roles. Leadership functions can also be performed by members of a team or individuals external to a team. A locus of leadership is defined using these characteristics of formality and position [83]. Within a student engineering design team, a formal, internal leader could be the team's project manager or chief engineer. A formal, external leader could be a faculty coach or industry sponsor. Informal, internal leaders could emerge to solve specific challenges while a mentor could serve as an informal, external leader. These relationships for undergraduate engineering teams are depicted in Table 2-4.

Table 2-4: Locus of leadership adapted from [83] **and presented in** [43]

<table>
<tr><td></td><td colspan="3">Formality of Leadership</td></tr>
<tr><td rowspan="3">Locus of Leadership</td><td></td><td>Formal</td><td>Informal</td></tr>
<tr><td>Internal</td><td>Team Leader
Project Manager</td><td>Leader for Emergent Problem</td></tr>
<tr><td>External</td><td>Faculty Coach
Sponsor</td><td>Mentor</td></tr>
</table>

2.5.4 Emergent Leaders

The existence of both formal and informal leadership structures implies that leadership functions may be distributed within the team. In this context, leadership may be understood as an emergent condition that may change with time [93,95]. Within the temporal context previously described, the state is impacted by previous activities and serves to influence future activities [81,95]. This concept of informal and emergent leadership does not imply the absence of a formal leadership structure [93]. Emergent leaders in this context are individuals performing leadership functions within the team whether or not they are formally appointed [95].

2.5.5 Research in Engineering Design Leadership

Table 2-5 provides a summary of the literature related to leadership in engineering design. Leadership is a part of the collaborative design taxonomy as previously discussed in 2.2.1 [2,20]. A survey instrument has been developed to investigate and leadership and communication within undergraduate design teams. The survey tool specifically identifies leadership styles within design teams and was intended primarily to be used with undergraduate design teams [96].

Table 2-5. Selected leadership research in engineering design

Type Study	Ref	Subject	Characteristics
Literature Review	[2,20]	Developed taxonomy of collaborative design	Collaboration
Case study	[96]	Developed survey instrument to study collaboration in student teams	Communication and Leadership
Case study	[62]	Investigated leadership in design teams	Transformational and transactional leadership
Case study	[97]	Investigated centrality of faculty coaches and graduate advisors in engineering design teams	External Leadership structure
Case Study	[68]	Impact of position of leader in communication network on creativity	Communication and leadership
Case Study and Simulation	[84]	Leadership style on complex functioning	Leadership Style
Case Study	[98]	Emergence of cultural boundary spanners	Boundary Spanners
Case Study	[99]	Impact of team context/environment in cross-functional, distributed teams. Suggests effective and supportive internal and external leadership important to effectiveness	Collaboration and Distributed teams
Case Study	[28]	Identifies lack of common vision as impediment to success in globally distributed teams	Distributed teams
Case Study	[100]	Establishment of minor program at University of TN to address engineering communication, leadership and teamwork	Education

Transformational and transactional leadership has been researched in undergraduate engineering design teams in a case study. The case study used observation to identify the occurrence of transformational and transactional leaders within the team.

Design reviews were used as the environment for observations. The authors concluded that student novice engineer leadership was primarily transactional [62]. By observing the activities of team members within design review meetings, the researchers focused on internal team leadership.

Leadership external to the student design team has been considered in addition to internal leadership studies. One study investigated the centrality of faculty coaches and graduate advisors in undergraduate teams. The coaches and advisors are in formally appointed leadership roles; however, they are not members of the team performing team tasks. The leadership was evaluated using statements from the multi-factor leadership questionnaire. This questionnaire was developed to evaluate leaders from the perspective of transformational and transactional leadership.

2.5.6 Interventions

Team performance interventions have been researched and include leader briefings and team interaction training [101]. While not in an engineering context, their research indicated that enhanced leader briefings were an effective means to enhance team performance. Leaders required instruction (or a script in the experiment) to provide the briefings. In consonance with team training, shared mental models were achieved that enabled the teams to improve their performance. Leader interventions could potentially be developed to enhance leader performance and consequently team performance within the context of engineering design teams. Leadership and teamwork interventions are not within the scope of the research; however, they do serve as an underlying motivation for this research. Descriptive research can provide a basis for future intervention development. The intervention meta-model is included as Figure 2-4 [101].

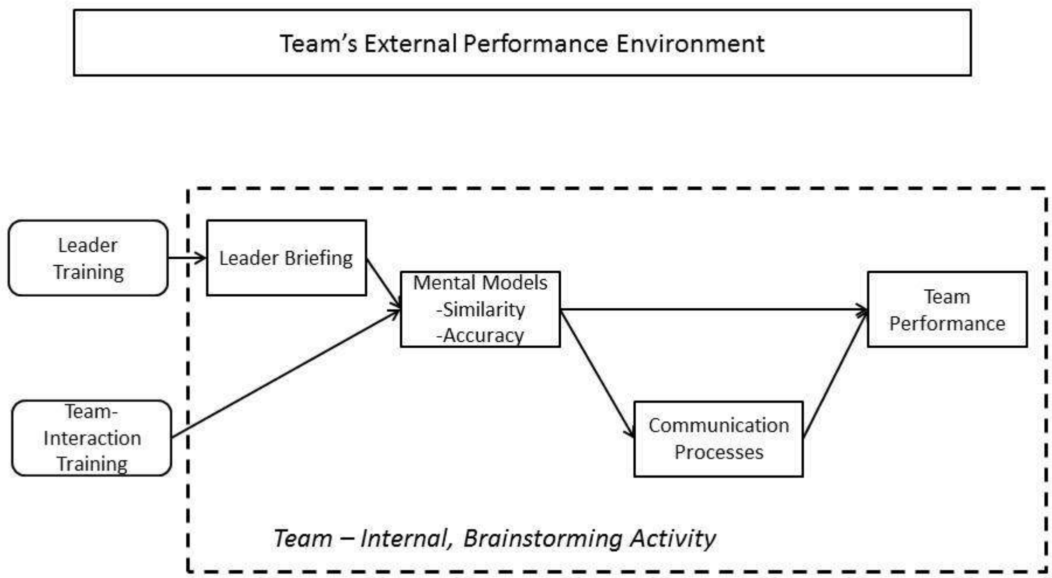


Figure 2-4. Leadership and team performance intervention model adapted from [101]**.**

In the figure, the team is conducting a brainstorming exercise. The leader briefing and the team-interaction training build a shared mental model for the team. While the leader briefing is conducted by the formal, internal team leader, the leader is trained by an external coach. In conjunction with effective communication, team performance can be enhanced by the team interventions of training and briefings. The briefings and training are specific to the environment of the team's performance [81].

2.6 Summary and Identifying the Gaps

Figure 2-5 shows the current progress through the dissertation. This chapter presented the background of the literature on collaborative design and teams. It then provided a proposed framework for classification of design review meetings that describes the type of meeting and its environment. Design review meetings provide an observation point for design teams during case studies. Finally, the literature on leadership theory and leadership research is summarized. This summary includes an overview of the functional approach to leadership that will be used as the theoretical basis for the research approach.

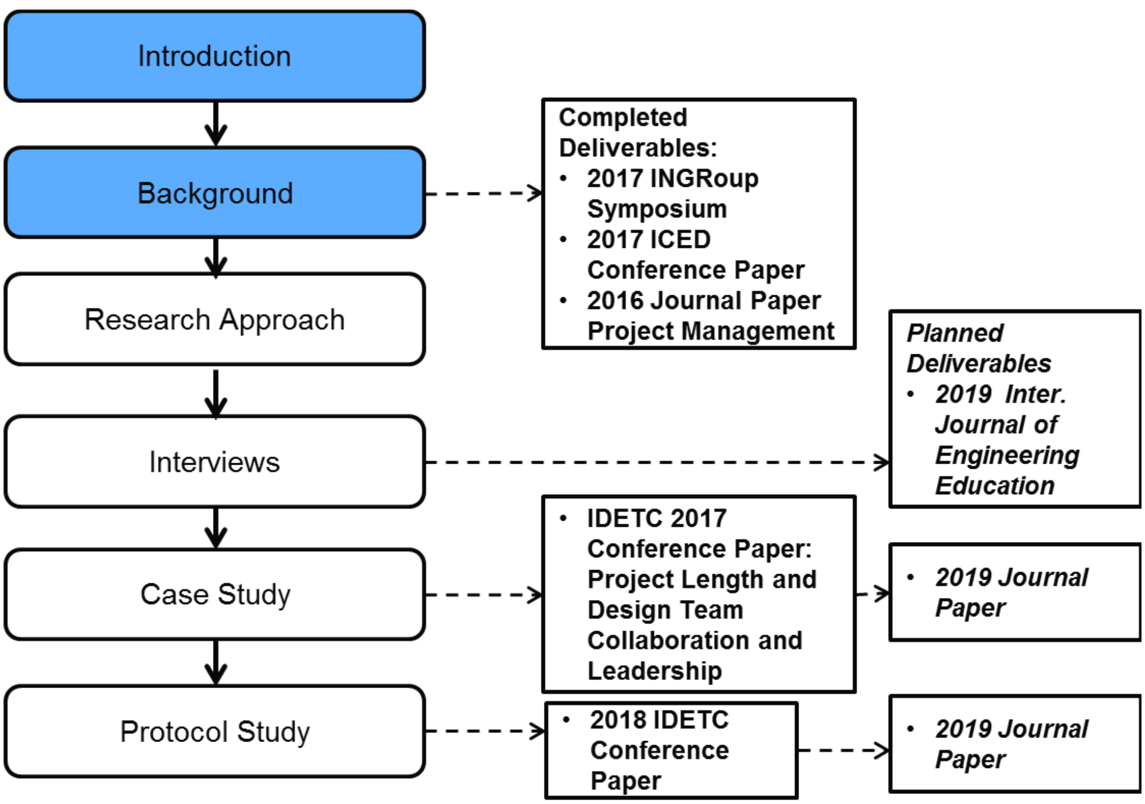


Figure 2-5. Dissertation roadmap

CHAPTER THREE: RESEARCH APPROACH

3.1 Research Objective

The objective of this research is to seek knowledge on the emergence and distribution of leadership behaviors in engineering design teams. This understanding will be beneficial to developing team and leader interventions that may find applicability in student and industry teams. It will also provide insights that may be useful in engineering design education and ultimately assist with the shaping and forming of capstone teams and courses.

3.2 Research Questions

To achieve this objective, a set of research questions have been developed to extend the understanding of leadership as presented in Chapter Two. The corresponding research questions are listed below:

RQ 1: How does leadership emerge in engineering design teams?

RQ 2: How are leadership functions distributed within the engineering design team?

RQ 3: How does composition (size, organization) impact leadership structure (position and functional distribution) in engineering design teams?

3.2.1 RQ 1: Emergence

The existing literature explores engineering design leadership from the context of contingent and transformational leadership frameworks. Research in psychology and management examine leadership in teams from a functional perspective and emergent states. There is little literature addressing the emergence of informal, functional leadership in engineering design teams within existing leadership structures. This research question seeks to ask how leadership emerges in engineering design teams to provide a description of emergence in novice design teams.

3.2.2 RQ 2: Distribution

An integral component of leadership structure is the distribution of the fulfillment of leadership functions within the design team. It has been theorized that functions may be performed within teams by both formal and informal, and internal and external leaders. Efforts to answer this research question will seek to determine and describe the distribution of leadership task performance amongst members within design teams. While efforts will focus on internal team leadership, there will be some consideration of external sources within the interview portion of research.

3.2.3 RQ 3: Composition

The collaborative design taxonomy suggests that team composition is coupled to team processes and performance. This research seeks to describe the impact of team size and organization on the informal leadership structure within teams. This knowledge can assist with the performance of multiple leadership functions within engineering design teams.

3.3 Research Overview

The timeline for the proposed research is presented as Table 3-1. Conference and journal papers are shown on the timeline when they were completed or when their completion is expected.

Table 3-1. Research Timeline

Activity	F 15	S 16	Su 16	F 16	S 17	Su 17	F 17	S 18	Su 18	F 18	S 19
Background development		**J**				**C** **C**					
Interview											**J**
• Development											
• Collection											
• Analysis											
Case Study											
• Preliminary Study					**C**						**J**
• Case 1											
• Case 2											
Protocol Study									**C**		**J**
• Development											
• Pilot											
• Primary Study											
Dissertation											
Deliverables found on timeline: C=Conference paper or abstract J=Journal Paper											

3.4 Research Approach and Methods

Multiple research methods were used to investigate the research questions identified. Interviews (Chapter Four), case studies (Chapter Five), and protocol studies (Chapter Six) were used to address the research questions. The techniques were combined to ensure that each question is investigated in the research campaign and that each question is triangulated using multiple methods when possible. A model representing the research question is depicted below in Figure 3-1.

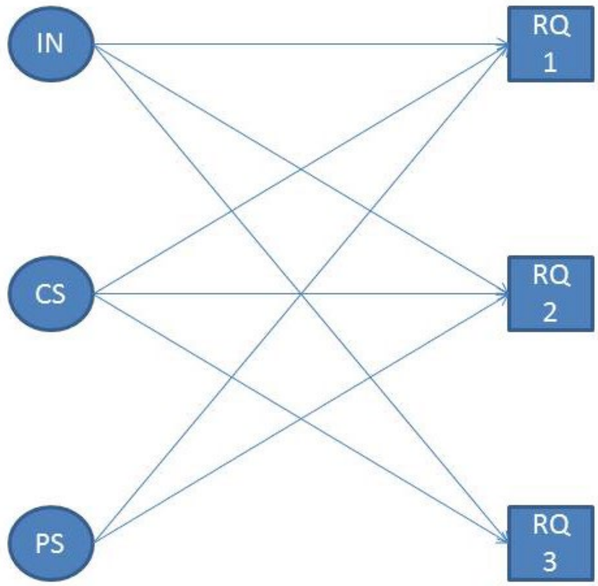


Figure 3-1. Graph of the research approach using multiple methods

The diagram represents the coverage of each research question by the individual research venues. Each circle represents a research method such as interview, case study, or protocol study. The research questions addressed are indicated in the square nodes on the right of the figure. Connections between a research method and a research question indicate that the specified method addresses that question. The areas of overlap, with multiple connections, indicate that the two research methods both address the research question indicated. For example, both the interview and the case study address research questions one, two, and three. This shared space demonstrates the triangulation afforded in addressing these research questions.

3.5 Summary

Figure 3-2 illustrates the position in the dissertation at the conclusion of the research approach. The research approach provided an overview of the research objective and the research questions. It also described the research methods that will be used in a multimethod approach to resolve the research questions. The next three chapters will detail the specific research methods that are proposed. Chapter Four describes the interviews that will be used to determine faculty perceptions of team formation and leadership assignment and emergence. Chapter Five describes a preliminary case study and proposes cases for further study. Finally, Chapter Six proposes a protocol study involving the activity of team function modeling within the stage of conceptual design.

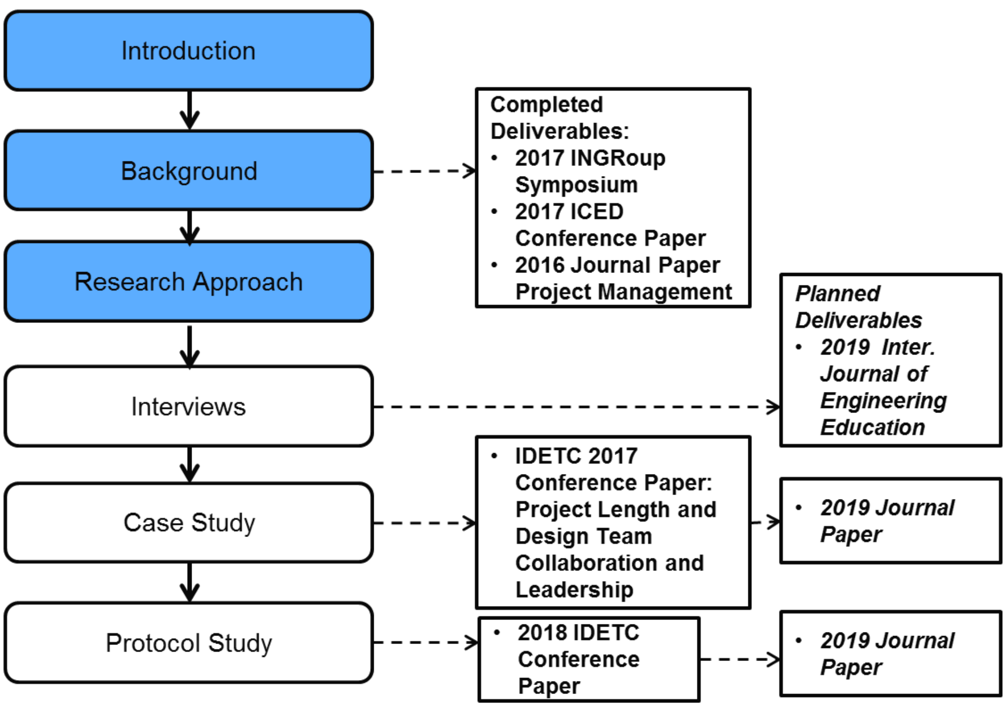


Figure 3-2. Dissertation Roadmap

CHAPTER FOUR: INTERVIEW STUDY ON LEADERSHIP

Interviews are a research method or tool that is used to collect human feedback, perception and judgment on a specific topic [102]. They are often used within a case study or other qualitative research study. They afford a more interactive data collection technique than a survey. Unlike surveys, the interviewer is able to explore ideas that emerge during the interview, and the interviewee is able to clarify responses and provide more nuanced responses than those provided in a survey [103]. Figure 4-1 depicts the use of interviews within the overall research approach. Interviews contribute to all three research questions by providing faculty perceptions on each topic.

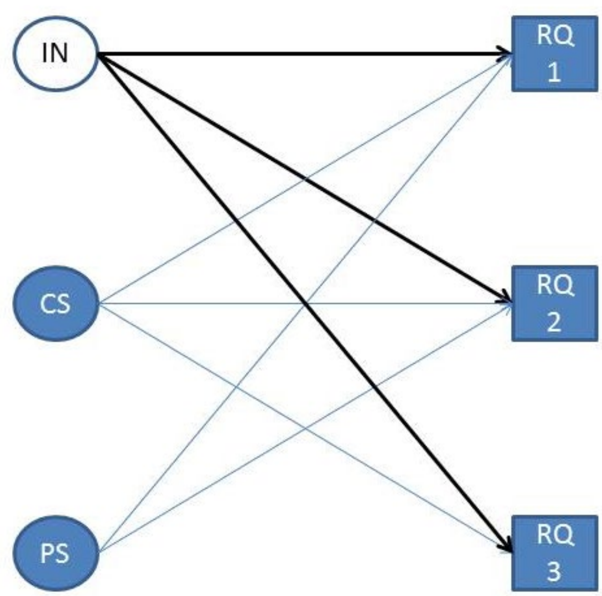


Figure 4-1. Interviews within the overall research approach

4.1 Interviews in Design Research

Interviews have been established as an effective tool in design research and have been used to study collaborative design processes [22,104,113,114,105–112]. For examples, interviews served as the primary data collection technique in a study of when and where collaboration occurs in design teams [52]. These interviews were all conducted with industry engineers at their work sites both to enable participation but also to maintain a natural context for the interviews that is consistent with the interview's subject. Interviews have also been used to identify the perception and interaction of employees engaged in the engineering change management process in industry [115]. This study used interviews to evaluate a process that is supported by tools. In these studies, the interviews were a core aspect of data collection and analysis. Another study used interviews to establish findings on the use of prototypes in industry [116]. The purpose of this study was to gain an understanding of how prototypes are used in engineering design. It also incorporated the analysis of physical prototypes as an additional research method. Table 4-1 provides a summary of design studies utilizing interviews as a research method.

Table 4-1. Summary of design research studies incorporating interviews

Ref.	Year	Purpose	Interview Goal	Additional Methods	Context
[104]	2013	U	V	E, Y, O	A
[105]	2013	T	M	M, Q	
[106]	2012	U	C	D	Q
[107]	2012	U	V	D	U
[108]	2006	U	C	D	U
[52]	2016	U	C	D	M
[109]	2012	T	C		G
[110]	2011	U	V	X	U
[111]	1998	U	V	P	U
[112]	2004	U	C		A
[113]	1997	T	E	M	F
[22]	2011	U	C	D	A
[114]	1998	U	V	E	M
[115]	2017	T	C	Q	U
[116]	2008	U	C	D	A

Purpose of Study: U = Understanding, T=Tool
Purpose of Interview: C = Core; E = Evaluation; M = Motivation; V = Verification; X = Explanation; U = Unclear
Additional Research Methods: D = Document analysis; E = Ethnography; M = Modeling; O = Observation; P = Protocol Analysis; Q = Questionnaire; V = Video; X = Experimentation; Y = Diary
Context of Study: A = Aerospace; U = Automotive; M = Mechanical; F = Manufacturing; G = Gas; C = Construction; E = Electronics; Q = Equipment; S = Software; R = Architecture; X = Complex Systems

4.2 Purpose of Study Interviews

The interviews are structured to provide insight into research questions one and two as indicated in Table 4-2. Specifically, the interview study was designed to elucidate faculty perceptions of leadership in design teams; and, the design team composition impact on the emergence of leadership functions and leadership structure in undergraduate student design teams. Understanding of faculty insights on leadership in design teams is used to further explore leadership through the development and conduct of a protocol study on leadership functions in design teams in Chapter Five. These insights are used to describe leadership in design teams and refine research objectives.

Table 4-2. Research questions addressed by interviews.

RQ 1: How does leadership emerge in engineering design teams?	
RQ 2: How are leadership functions distributed within the engineering design team?	
RQ 3: How does composition (size, organization) impact leadership structure (position and functional distribution) in engineering design teams?	

4.2.1 Interview Participants

Six interviews of mechanical engineering instructors have been recorded and transcribed. Participants were selected for the interview based on their experience composing and coaching undergraduate design teams. They are selected from two universities with engineering research programs and both undergraduate and graduate degrees including doctoral studies. The qualifying experiences include capstone design courses, team-based learning courses, creative inquiries, or extracurricular team advising. Some faculty also participated in industry design team during previous jobs. Five of the participants are permanent faculty members with doctoral degrees, while the final participant was a graduate student who completed a semester as the instructor of record for a capstone design course.

Table 4-3. Summary of participant design team experiences.

Total Participants	6
Years Experience at time of interview (Range)	2-12
Median, Years experience	5
Mode, Years experience	5
Mean	7.3
Total Schools (Instructor)	5
Participants who have worked in government labs	3

Beyond the requirement that each interviewee had composed and mentored undergraduate design teams, participants were selected to represent a variety of professional backgrounds. For example, participants were selected with backgrounds in different fields. Four of the six participants worked in government labs, providing a different set of experiences from the remaining participants. The range in years of two to twelve years (at the time of the interview) of experience advising undergraduate teams also ensures that perspectives collected are not limited to those with similar seniority and quantity of teams advised. In addition, while all the participants were currently employed at two research universities, their experiences include teaching and advising at a total of five universities. While participant backgrounds are provided in aggregate form, the specific background for each interviewee is not provided to preserve anonymity.

4.2.2 Interview Design

The interviews are semi-structured to best accomplish the purpose of obtaining faculty experiences and insights on research questions one and two. A semi-structured interview consists of planned questions to ensure the consistency of the interviews but allows the interviewer to amend or add interview questions in order to amplify responses or to develop new insights. The interview is designed to provide understanding of the core issue of faculty perspective on engineering design team leadership. The interview design and flow are depicted in a flowchart as Figure 4-2.

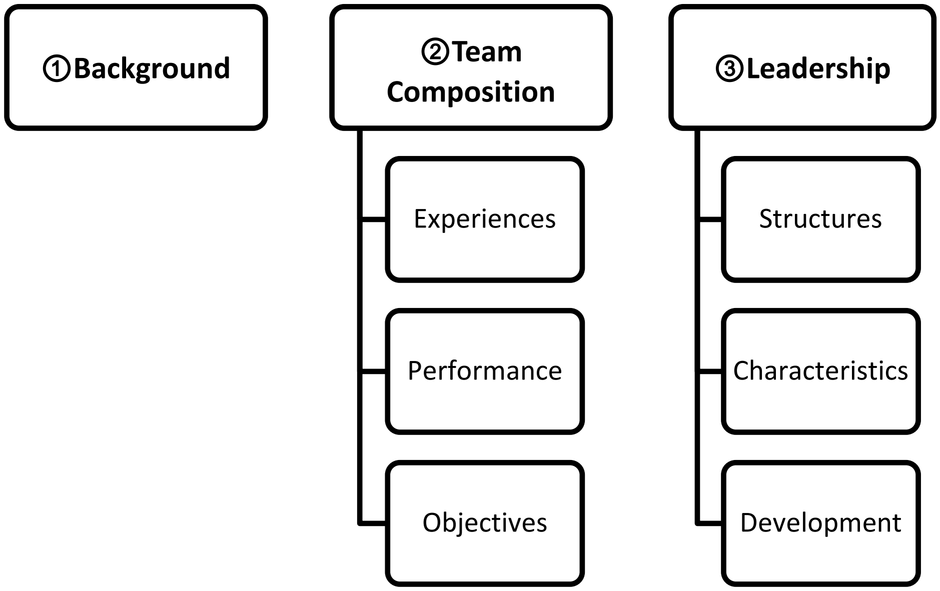


Figure 4-2. Interview flow chart.

4.2.3 Background Questions

The first block of interview questions asked the participant for basic biographical background material concerning their experiences coaching or advising design teams. This information could efficiently be asked in a pre-interview survey, reducing the length of the interview. However, it was included in the interview to encourage the participant to recall past experiences prior to asking more detailed questions and to improve the flow of the interview. Consideration to establishing these questions as a pre-survey interview would be warranted if the survey was also used as a screening tool to determine qualified participants or to tailor interview questions to the background of specific participant.

When faculty indicated industry or unique design team experiences during the background portion of the interview, they were asked about how these experiences were similar to, or differed from, academic design teams when appropriate. Interviewees were asked follow-up questions to ensure that it was clear in their responses which information pertained to university experiences and which were specific to industry experiences.

4.2.4 Team Composition

The second portion of the interview focused on the faculty member's experiences composing teams. Capstone teams are composed using a variety of methods and foundations. Research has been and continues to be conducted to establish the impact of team composition on the performance of the team and the quality of the learning experience for the students [21,117]. This portion of the interview captures the preferences and practices of the interviewees and their perceptions of the effectiveness of these methods.

4.2.5 Leadership

The final portion of the interview concerns leadership in student design teams. These questions query the faculty on the leadership structures, characteristics and functions within their student design teams. Questions are open ended to establish which characteristics and functions are observed or valued by the participant while taking care not to lead them to a specific response by suggesting particular characteristics or functions. The latter questions of this interview block are designed as repetitive. While their usage may validate or amplify previous responses, they may be omitted to preserve a consistent interview length. The desired information is often provided in previous responses and may not be necessary to complete the interview. The interview questions are listed in Table 4-4. Questions are numbered according to their section of the interview. Formation questions are labeled as "F" (F1-F7) and leadership questions are indicated as "L" (L1-12).

Table 4-4. Interview questions for team composition and leadership interviews

Item	Question	RQ
F1	How many years, and at what institutions, have you instructed engineering design courses that include collaborative or team-based design (faculty)?	B
F2	What other experiences do you have with design teams (creative inquiries, industry, research projects…)?	B
F3	How do you decide how teams are composed or select members for specific teams? What factors are considered?	3
F4	How many members do you typically place on each team, and how is the size of the team determined?	3
F5	When you think back on your experience building teams, what do you think has been most effective and what has not worked as well?	3
F6	Has your approach to forming teams changed over time based on your experiences, and if so how?	3
F7	What is your objective when you build teams: performance of team, satisfaction of team members, other objective?	3
L1	How do your teams typically develop leadership roles and structures?	1, 2
L2	Do the students typically have formal leadership roles?	1
L3	What roles are typically established? Are they coached to establish specific positions, or do they determine their own roles?	1, 2
L4	What characteristics have you observed that make students effective leaders within their teams?	1
L5	How can we help design teams develop better leadership skills?	1, 2
L6	Do team leadership roles generally stay consistent throughout the process or do they change or evolve?	1, 2
L7	What characteristics have you observed that make students ineffective leaders or struggle with leadership roles?	2
L8	How big of a role do you believe informal leadership has in design teams?	1, 2
L9	Based on your experiences, what do you think is the most effective means to determine leadership roles for teams?	1, 2
L10	Based on your experiences, how can we help students develop leadership skills?	1, 2
L11	What do you think are important leadership skills?	2
L12	How can we help student leaders succeed?	1
Item Numbering Nomenclature: F=Formation or background information; L=Leadership Note on RQ: B=Background only		

4.2.6 Conducting Interviews

Interviews were recorded to enable full or partial transcription following interview completion. Participants were provided the option to conduct an unrecorded interview if they were uncomfortable with recording. No participants elected this option. Notes were taken during the interview to enable production of a post interview summary. The summaries for each interview were provided to the participant, normally within 48 hours of interview completion. Faculty were asked via a follow-up email to review and provide feedback if desired. The e-mail indicated that if no response was provided within seven days, the interview summary would be considered approved. They were also given the opportunity to provide any additional thoughts on the interview questions if desired.

The interviews were structured to be completed in a time frame of 45 to 60 minutes. The first interview was completed in 49 minutes. This validated that the allotted time was sufficient to conduct the interviews. This time enabled comprehensive coverage of the necessary questions without allowing the interview to lose focus due to fatigue. If the interview was not complete at the end of 60 minutes, a second session could be scheduled to complete the interview, however, this was not necessary as each of the interviews was completed in the allotted time.

Interviews were primarily conducted in the office of the faculty member (4 of 6). The office provided a comfortable environment for the participant without introducing the variable of an unfamiliar environment. By scheduling the interview in advance, outside distractions such as telephone calls and emails were eliminated. One interview was conducted by telephone due to the location and availability of the participant. One interview was conducted in a conference room since the graduate student instructor’s office was not sufficiently private for a focused interview. Interviews occurred between 28 September 2016 and 4 April 2018 as detailed in Figure 4-3.

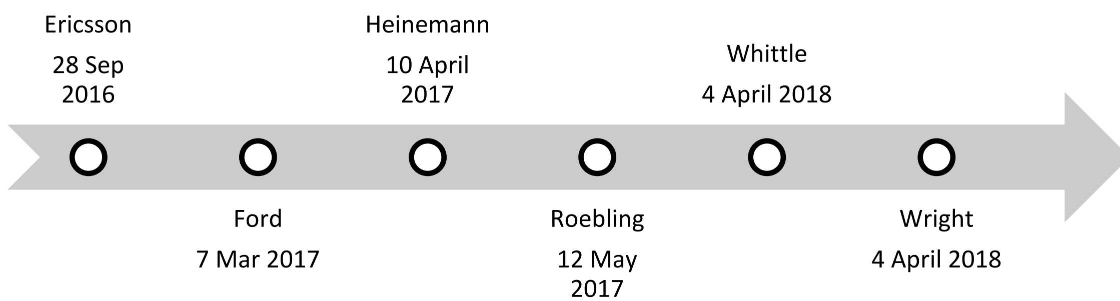


Figure 4-3. Timeline of interview conduct

Each participant is provided an alias in the timeline (Figure 4-3). These aliases are used throughout this dissertation when referring to specific participants. Aliases do not indicate characteristics of the participants and are alphabetically ordered to represent the chronological sequencing of the interviews for convenience. Early interviews were used to corroborate and inform design of the case study and protocol study. Interviews were conducted to provide a wider range of experiences in the participants.

4.3 Interview Analysis

The interview recordings were transcribed and analyzed using three techniques. The first level of analysis is surface level responses to interview questions. The second level of analysis is from elaborative and inferred coding. A final level of analysis is conducted using latent semantic analysis tools[1]. Each of these analysis layers provide

[1] Latent Semantic Analysis at Colorado University Boulder, http://lsa.colorado.edu, accessed 12/11/2018.

unique perspective on the perceptions of the instructor participants. The first layer of analysis consists of the direct responses of the interviewees to each question. The additional analysis techniques are intended to provide additional insights into the relative significance of leadership concepts, correlation between different topics and contexts, and similarities between individual participants.

4.3.1 Code Development

The code includes a combination of elaborative categories and inferred categories based on linguistic analysis. Elaborative coding is the application of a theory or framework from previous literature and research to the development of a coding scheme [118]. The categories are based on the functions, or behaviors, of leadership [83]. This is appropriate as the leadership functions are a mature concept and have been applied in numerous organizational psychology and management studies [81,83,119]. Categories are also inferred based on linguistic analysis or word counts from the initial interview summaries. Frequently used words are used to infer themes that are included in the coding [120]. The recording unit is the sentence.

4.3.2 Inferred Codes

Interviews were summarized, normally within 48 hours of completing the interview. Notes taken during the interview were used to summarize the participants' responses. Recordings were used to clarify any ambiguities in the interviewer's notes. These notes were then provided to the participant for an opportunity to confirm or clarify responses. A suspense date of approximately one week was provided for response.

Interview summaries clearly indicated that the instructors consistently noted the correlation of communication to successful leadership and teamwork. This was later confirmed by transcribing the interviews and using “Tagcrowd” to count and visualize frequently used words[2].

An example visualization is included in Figure 4-4. The word “communicate” is found as one of the common words in each of the interviews depicted. This supports the initial finding from the interview summaries. As a result, communication is incorporated as an inferred coding theme. Skill, mode, and frequency were included as subsets of communication to better understand what aspects of communication were considered. A broader category of communication was provided in case it was addressed in a more general sense. The most frequently used words from two of the early interviews were then compared to identify the union of the two sets.

[2] TagCrowd, https://tagcrowd.com, accessed 12/11/2018.

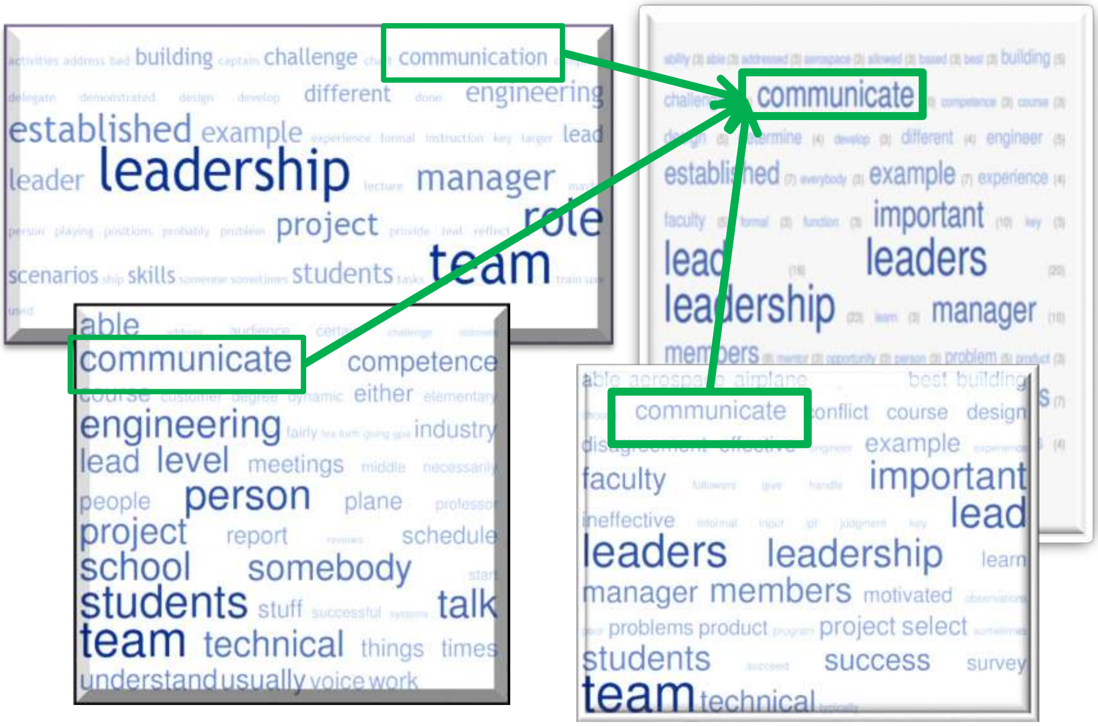
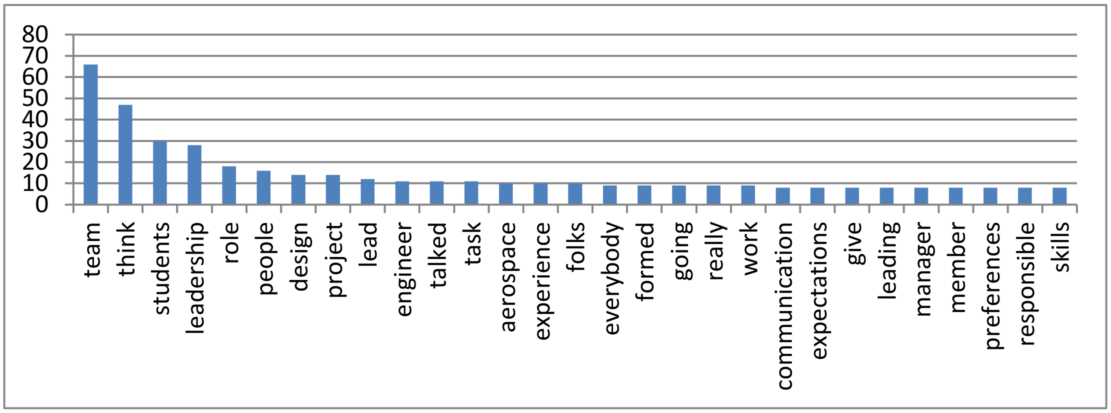
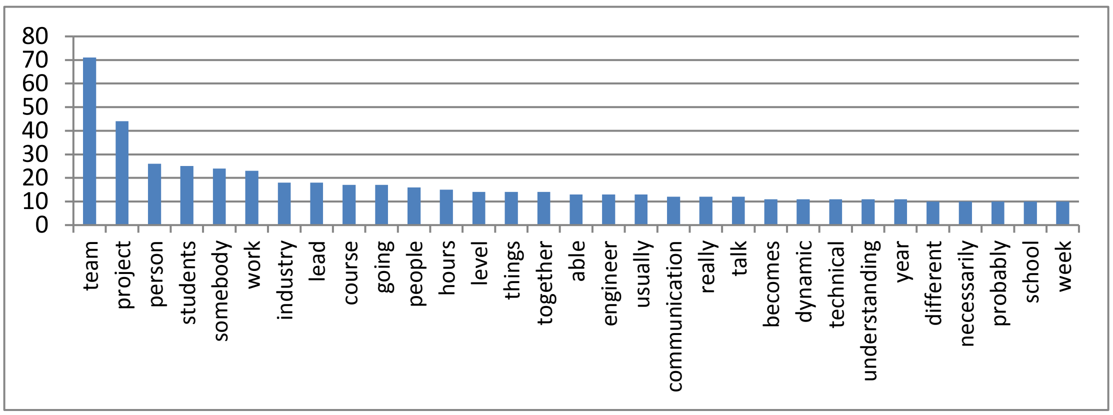


Figure 4-4. Example word visualization results used in thematic code development.

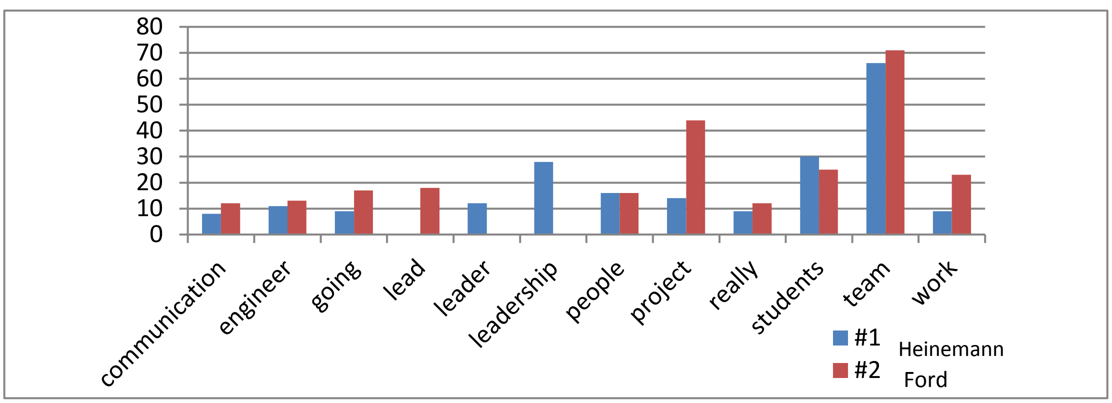
Initial development of inferred themes was conducted using the Tagcrowd web application, an open source tool that provides word counts and frequency visualization. The tool has been the subject of social media and software design research [121]. The specific functionality used was to obtain word counts. The application contains a common word stop list and allows the user to designate additional stop words, minimum frequency displayed, and other limited options. Transcripts were imported into a spreadsheet to support future coding. The leadership and formation sections of the interview were separated into distinct sheets to enable independent analysis and removal of interviewer questions. Two sample results are illustrated in Figure 4-5.



(a) Word Count for Heinemann Interview



(b) Word Count for Ford Interview



(c) Comparison of Word Counts for Heineman and Ford

Figure 4-5. Word counts from two interviews used for thematic development

Additional categories were inferred in a similar manner, although in some cases it was necessary to combine similar words into a common theme. For example, "team" is the most commonly used word in both selected interviews. "Team" is an important part of the context for leadership in student design scenarios. "Project" is also a frequent word in both transcripts and is also a part of the leadership environment. Less obvious but still clear are the words used for different fields (aerospace, industry) and a wide variety of words used to describe the subject product. An overall theme of context was developed to code for the team, the field, the project and the product.

Figure 4-6. Inferred themes and codes for leadership interview transcript coding.

Leadership is captured in the elaborative coding in terms of the individual functions. However, leadership is referred to by interviewees in a variety of other means. Leadership was discussed in terms of positive or negative leadership characteristics; and formal or informal leadership structures. In many cases the term "leadership" is used but its specific definition or context is not explicitly stated or clearly implied. This result was not unexpected due to the nearly infinite quantity of formal and working leadership definitions in common use. A leadership theme was established to capture codes for these differing aspects of leadership. Finally, roles were added as a theme to capture leader, member, and follower.

4.3.3 Coding Example

Figure 4-7 is a selection from one interview transcription and the associated coding. The sample is from question four and includes both the interviewer's question and the beginning of the response. A portion of the interviewer's question is not displayed (replaced by ellipsis) to retain anonymity. Only the response is coded. Sentences within a response are numbered in the order recorded and are indicated by the superscripts (from 1 to 6) below. In sentence one, Dr. Heinemann clearly addresses the role of member within the context of the team. There is not a specific reference to communication; consequently, this field is left blank. The function of performing task is clearly addressed in the first portion of sentence one and is annotated in the function field. The final field of "notes" provide notes to highlight why a specific field was selected as it was. Leadership and modifier are left blank in this excerpt as they are not required.

Interviewer: Of all these teams you've observed … what characteristics of students have you observed that make them more effective leaders?

Dr. Heinemann: [1]OK from a student perspective I believe it's a student who's willing to both complete the tasks, that they're responsible to be a contributing member or engineer in the team as well as take on additional tasks that provide some direction. [2]And again this is more along the lines of project management I believe. [3]That there needs to be a project manager to keep people on task. [4]But, but, but, but this is really important. [5]A student who is only a project manager and not a contributing engineer to the team, is not very well respected or well liked within the team. [6]So I think that that sort of is the thing that I've observed.

Question	Sentence	Comm.	Roles	Leadership	Context	Function	Modifier	Notes
4	1		Member			PT		Complete the tasks
4	1					SP		Tasks provide direction
4	2					SP		more along lines of project management
4	3		Leader			MG		keep on task
4	5		Leader		Team	PT	Negative	not respected

Figure 4-7. Sample section of coded interview.

Figure 4-8 is a second selection that demonstrates the remaining fields not addressed above. This selection is from Dr. Ford's interview and is also in response to question four addressing characteristics of successful student leaders. Dr. Ford responds that effective leaders are generally strong communicators and are technically competent. The communication field is marked with the "skill" code corresponding to the comment that student leaders "can actually communicate engineering to a lay audience." Technical competence is addressed as a leadership characteristic in the leadership field. Both are annotated in the notes section for future reference.

Interviewer: What has made for effective student leaders? Or I guess you could say successful...

Dr. Ford: [1]Yes, so they have some level of technical competence and can actually communicate engineering to a lay audience.

Question	Sentence	Comm.	Roles	Leadership	Context	Function	Modifier	Notes
4	1	Skill		Characteristic	Team			Technical competence, skill communicating to different audiences

Figure 4-8. Communication and Leadership fields sample (from Dr. Ford interview).

4.4 Interview Results

As discussed in 4.3, the interview results are studied in three layers. The first layer is a summary of the direct responses of instructors to the interview questions. Second, is an analysis of the interview coding. The final layer is a latent semantic analysis. The second and third layers are designed to provide insights that may not be apparent from a simple summary of the faculty responses.

4.4.1 Faculty Responses

The first two interview questions were designed to provide an overview of each faculty member's background and experiences. This background information is included in the summary of participants provided in Table 4-3. These questions were also intended to provide prompts for the faculty to begin reflecting on their experiences forming and advising design teams. It is anticipated that these experiences will form the basis, or at least inform, their perceptions and associated responses to the remainder of the interview questions.

4.4.1.1 Team Formation and Composition

This portion of the interview asks the faculty to describe the composition of the teams they have composed and advised. It also asks them to describe the methods they have used to compose teams, to comment on the effectiveness of these methods, and to consider if they have or would change these methods. This portion served multiple purposes within the construct of the interview. First, it was used to help refine the focus of the study and the research questions. It also served to provide context to the heart of the interview: the leadership portion. The composition of the teams and their formation methodology are an integral part of the collaborative design team. They also provide insight into the leadership function of team composition in student teams. A considerable portion of this function is performed by the faculty as an external, formal leader. Responses to these questions elucidate this functional behavior within the broader context of teams within the larger system that includes faculty and sponsors although they are not within the team boundary. Table 4-5 is a summary of the responses to the team formation portion of the interview.

Table 4-5. Team Formation Interview Responses

Question	Response	Quantity (out of 6)
F3	Skills	5
	Preference	5
	Algorithm	2
	Personality	1
	Location	2
	Leadership	1
F4	4	5
	5	3
	6	2
	7	1
	8-12	4
F5 (+)	Balanced abilities	2
	Balanced skills	2
	Experience	1
	Work well with others	1
	Communication skill	1
	Work ethic	1
	Change teams	1
	Delay formation	1
	Team names	1
F5 (-)	All high GPAs	2
	Personality challenges	2
	Not balanced skills	1
F6	Yes	4
	No	2
F7	Mix of Performance and Learning Experience	

The instructors interviewed have formed teams by a variety of techniques. Generally, the instructors used some combination of the techniques listed in Table 4-5. The most common components for team member selection are skills and preferences: five of the interviewees used this method to select team members. In this case, the faculty reported assessing the students' functional skills prior to team member selection. This assessment is often informed by a self-assessment survey provided to the students prior to the beginning of class. At the highest level, skills could be indicated by the student's major:

such as mechanical, industrial, civil, aerospace, electrical, and computer engineering. Other indicators could be the student's experiences in cooperative programs or job experiences. Sometimes skill with prototyping and fabrication are considered. However, other teamwork skills such as leadership can be considered. Five of six interviewees also considered student preferences when determining team membership. Students may be allowed to indicate specific students they would specifically like to, or not like to, work with. They may also be given an opportunity to indicate their preference for a specific project.

Additional approaches were described at lower frequencies. Two instructors were engaged in a project that uses an algorithm to determine team membership. A computer program uses the algorithm to consider five categories: motivation, technical skill, social skill, leadership, and location (logistical considerations). Location was a consideration in this project because the students were distributed nationwide. While this approach considers a wide span of factors, one instructor reported it does not consider the personality of team members. One faculty member uses Meyers Briggs Type Indicator (MBTI) to assess personality and balance teams by the resulting personality types. MBTI has been used in student engineering team formation [21]. Additional study has been conducted on personality self-assessment using the Five Factors model that provides a foundation for future research of the use of personality assessments in design team composition [122].

4.4.1.2 Developing Leadership Structures

Most of the faculty members interviewed reported a similar approach to developing leadership structures in student teams as shown in Table 4-6. Students are generally allowed to select their formal leaders. Some faculty require their student teams to designate leaders by a specific date, early in the course. Others observe and allow the teams to develop roles without specific deadlines. However, in all cases, formal roles were identified. Students established leadership positions even when not specifically required to establish these roles.

Table 4-6. Leadership interview responses.

Question	Response	Quantity (out of 6)
L1	• Students Select Formal Leaders • Instructor Selects Formal Leaders • Limited training often incorporated to guide selection	5 1
L2	• Formal Leadership Structure is identified	6
L3	Roles Established: • Team Leader • Project Manager • Chief Engineer • Secretary • IPTs • Treasurer	
L6	Rotation of Roles Reported	3
L4	Positive Leadership: • "Get hands dirty" • Communication • Positive, conscientious, selfless, trusted, motivated, competent, participative	 3 3
L7	Characteristics: • "Can't communicate" • Arrogant • Overbearing • No feedback, cannot manage up	 4 1 1 1
L8	Informal leadership plays a significant role	6
L5, 10, 12	• Team building exercises • Feedback • Model good leadership (learn from bad) • Teach conflict management	

Dr. Roebling selected team leaders and chief engineers. The selections were made after having an opportunity to observe the students and their interactions. The students were not required to accept the role, mitigating the possibility that outside commitments might prevent them from filling it successfully. These selections were made on design teams of ten to twelve members and on distributed teams. Further research could be conducted to explore the impact of self-selection or faculty selection on the success of teams and the development of leadership skills. The short time frame of the projects generally requires early selection of leaders while the students have had a limited time for team formation and observation of teammates.

Formal leadership roles generally stay consistent throughout the projects, although Dr. Wright actively encourages members to rotate roles during the early stages of the project. This approach was expected to challenge the students to accept new roles they might not be comfortable with at first. Ericsson, Whittle, and Wright reported occasional changes in formal roles, however, the formal structure usually remained stable. Sponsor-initiated changes to the project impacted the structure in one case. The sponsor decided to select one concept from three project teams at the project's midpoint. The individual teams were then reorganized as a system of teams with each team responsible for one sub-assembly of the overall product.

4.4.1.3 Leadership Roles

While the student design teams established a variety of leadership roles, faculty perceived that most teams did have core common roles. Teams generally established a technical lead and a project manager although some established only one primary leadership role to manage both sets of responsibilities. The technical lead was identified as a chief engineer or team leader and was responsible for coordinating and leading the engineering tasks. Roles sometimes included leadership of sub-assembly efforts, particularly on larger teams with ten to twelve members. Additional roles were identified such as treasurer and secretary.

4.4.1.4 Characteristics of Effective Leaders

Faculty were directly asked to identify leadership characteristics for effective and ineffective leaders. Strong communication skills and the willingness to "get their hands dirty" were the most commonly identified characteristics of effective leaders. Ericsson, Heinemann, and Wright all cited the willingness to perform the engineering tasks with team members rather than simply attempting to direct the team as a factor in leader success. This characteristic can be related to selflessness which is also noted by faculty. Communication skill is noted by Ford, Heinemann, and Whittle.

Communication ability was a common theme throughout the interviews and not only in the question specifically requesting that the faculty identify leadership skills. This is consistent with leadership literature and is further explored in 4.3.5 [36]. Communication with team members and people external to the team are both addressed. Dr. Ford highlighted the need to communicate technical information to non-engineering audiences such as sponsors and customers. These skills apply to many, if not most of the leadership functions. They correspond directly to sense making and boundary management.

Technical competence was also highly valued by the faculty advisers. This was identified as a requirement for effective leadership although it is not considered sufficient without other skills such as communication. Technical competence, however, is not only related to academic or theoretical skill. Dr. Ford stressed that competence in manufacturing and assembly of prototypes are equally valuable. Multiple personality traits and characteristics were addressed individually by faculty. Dr. Whittle identified conscientiousness. Roebling identified motivation; while, Ericsson addressed positivity.

4.4.1.5 Characteristics of ineffective Leaders

Detrimental characteristics were described both when explicitly requested and as traits to avoid when describing effective leaders. The inability to communicate was the most frequently cited and is clearly identified as the opposite of the positive characteristic identified in 4.3.4.4. Arrogance, or overconfidence, was identified by Ford; and Ericsson indicated that ineffective leaders are sometimes overbearing and don't allow members to participate. Additional characteristics correlate to a failure to perform specific leadership functions. "Can't manage up" is closely related to boundary management while not providing feedback was also mentioned as a flaw. The failure to "follow-up" on tasks corresponds to a lack of monitoring and guidance. Both were identified by Whittle.

4.4.1.6 Leadership Development

Each interviewee was asked to provide their thoughts on effective means to develop better student leaders. Their responses can be grouped into four categories: leadership opportunities, mentorship and feedback, skills training, and team building exercises. Leadership development can occur during any team project or event in the curriculum. These team events were acknowledged as opportunities for students to develop leadership and other teamwork skills. This development can occur for both leaders and followers in the teams. Leaders have the opportunity to develop skills from the challenges presented, while followers can observe the effectiveness, or ineffectiveness of the leadership techniques employed. In addition to, or in conjunction with, these team projects throughout the curriculum, team building exercises were discussed as a possible means to provide additional experiences. These could be short duration design challenges that can be incorporated into team meeting at the beginning of a project or during classroom time.

Faculty members advising design teams can mentor and provide feedback to student team members and leaders. They also have opportunities to model effective leadership techniques to students. One faculty member noted that even when modeled behavior is not perfect, it can still be used as a teaching point if recognized and acknowledged within the context of team meetings. However, these interactions can be challenging since the faculty only have limited observation of team interactions.

Conflict resolution training was suggested by one interview participant. Students have diverse team experiences and there are corresponding differences in their experiences resolving conflicts during team interactions. Faculty acknowledged providing some guidance on leadership and teamwork skills, but, recommended providing additional training on some skills. Ford and Heinemann acknowledged that leadership development can be difficult due to limited observation time and other challenges.

4.4.2 Coding Results

Interview coding is intended to provide additional quantitative data to support the interview responses. It also reveals connections within the data that may not be readily determined from the first level of analysis in 4.3.4. This coding process is central to a systematic approach to analysis of the interviews' content [123].

Detailed coding required transcription of the interviews. The transcription time to recording time ratio was approximately four to one (4:1). The transcripts were then copied into a spreadsheet with separate sheets for questions and responses. The formation and leadership portions of the interviews were also placed into separate sheets. Interviewer statements were considered for context but removed from the coding. Only the central leadership portion of the interviews were coded. The interviews were simultaneously coded for the elaborative and inferred categories described in 4.3.1. Coding time for the interviews was approximately three hours to one hour of recorded interview.

4.4.2.1 Leadership Functions

The leadership functions were coded as they occurred, by sentence. The overall frequency of occurrence is represented in Table 4-7. Behaviors from each function type or phase (transition, action, relational) were addressed. All functions except for "define mission" and "empowerment" were addressed at least once in the interview leadership responses, although a definition of leadership or a list of its functions were not provided. "Define mission" was addressed in the composition portion of the interview; however, this portion of the interview was not coded. This does not imply that each faculty member addressed every function, but each function was addressed in the aggregate response.

Table 4-7. Leadership function frequency of occurrence.

	Functions	Occurrence
Transition	Compose Team	3
	Define Mission	0
	Expectations and Goals	1
	Structure and Plan	10
	Training and Development	68
	Sense Making	2
	Provide Feedback	12
Action	Monitor and Guide	15
	Manage Boundaries	23
	Challenge Team	1
	Perform Team Task	9
	Solve Problems	4
	Provide Resources	2
	Encourage Self-Management	4
Relational	Support Social Climate	11
	Consideration	12
	Empowerment	0
	Total	177

Training and Development was the most frequently discussed leadership function. This is related to a specific question being directed to each participant addressing training and development. It could also be related to the prominence of training, education, and development in the mission of instructor. Boundary management was the second most frequently occurring. Boundaries discussed included boundaries between the design team and faculty advisor, the design team and sponsors, and between design teams. This function was performed not only by student leaders, but by faculty managing boundaries. This bi-directionality of the function and the centrality of faculty advisors in this role relates to its frequency. However, faculty did mention the significance of this function to team and leader success.

Each faculty member addressed monitor and guide (15 instances) at some point during the leadership discussion. For example, Dr. Heinemann discussed that the leader must "provide some direction" and "keep people on task." Consideration and provide feedback were addressed nearly as often as monitor and guide (12) but the distribution was less even. Consideration was addressed by four and provide feedback by three instructors.

The only relational function not addressed was empowerment. However, support social climate and consideration were frequently addressed. In this way, although empowerment was not specifically addressed, relational functions were commonly addressed. Other infrequently addressed behaviors include sense making, expectations and goals, challenge team, and provide resources. Expectations and goals may be less frequently addressed since faculty normally provide these expectations for the teams. Team charters or additional tools, however, are an example of a tool that can be used to help strengthen this function within the core student team. Resources are also normally provided by the faculty and sponsors and may not be routinely associated to the student leadership function and were addressed in the team composition portion of the interview (although not coded). Sense making will be much more closely addressed during the protocol study discussion (6.3).

4.4.2.2 Roles

The roles theme captures whether the recorded unit refers to a leader, a member, or a follower. The prominence of leadership occurrences is expected due to the leadership focus of the interview. However, the leadership does not exist without individuals who are influenced, or followers. Members are individuals on the same team with the leader in the context of the interviews. Leader Member Exchange Theory focuses on the relationship between leaders and members as discussed in 2.5.1.4. The occurrences of leader, follower, and member roles in the interviews are summarized in Figure 4-9.

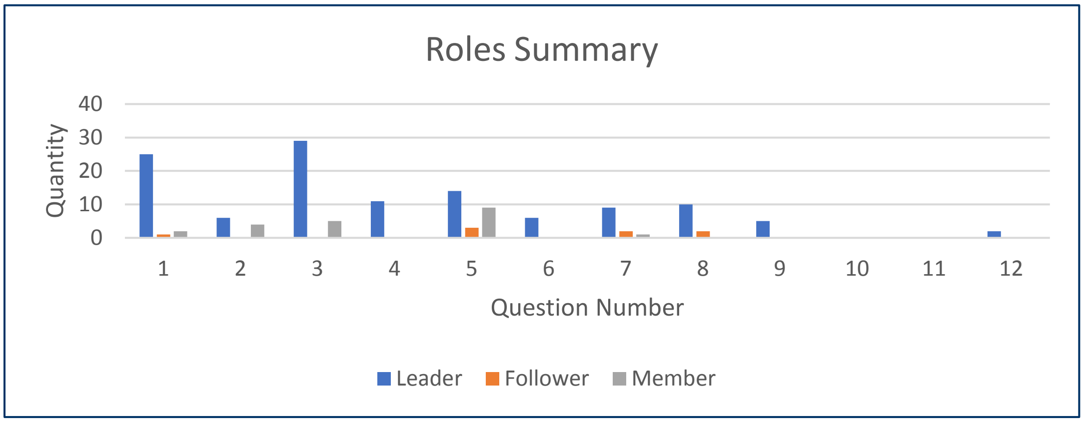


Figure 4-9. Leader, follower, and member role occurrences in the leadership portion of interviews

Leader roles account for 80% of the role occurrences in the five coded interviews. Member references account for 15% with follower references are the remaining 5%. Leader references are most frequent when discussing establishing leadership structures and formal roles. Explicit follower references were relatively infrequent and occurred in different portions of two interviews. The most frequent occurred in the question regarding leadership development. Specifically, Dr. Wright noted that it is important to learn to be a follower to learn leadership skills. Dr. Roebling reinforced this by stating that sometimes the best leaders are also the best followers. He also noted that some student leaders are better suited in a follower role because of their approach to followers. The remaining follower annotations involved the importance of having followers on teams and defining informal leaders by their relationship with followers.

Figure 4-10 demonstrates the coded roles within Dr. Heinemann's interview. The data represent individual sentences with a "role" theme coded. The roles are recorded on the vertical axis and the questions are indicated on the horizontal axis. This interview included two references to follower roles in reference to ineffective leadership characteristics (question seven). Member references are in question five, regarding training and development. The leader roles are primarily concentrated in the first three questions concerning leadership structures and roles.

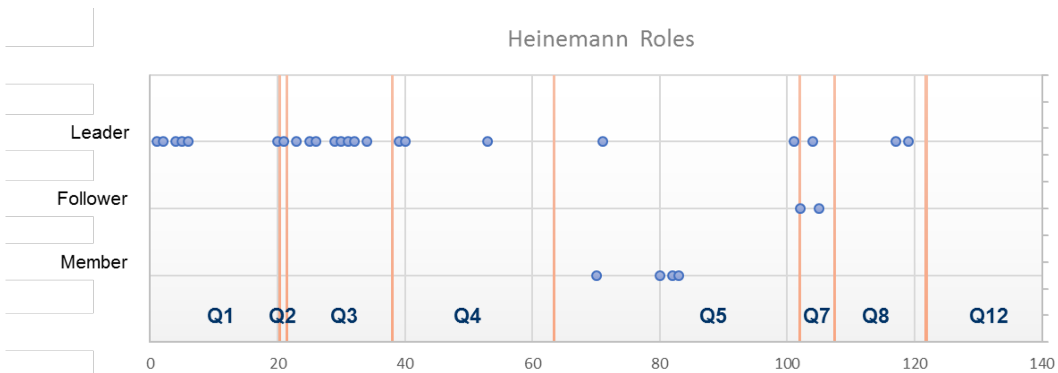


Figure 4-10. Depiction of role references in Dr. Heinemann's interview. Roles are specified on the vertical axis and questions on the horizontal axis.

4.4.2.3 Leadership Characterization

The elaborative themes addressed the leadership functions; however, a leadership characterization theme was provided to capture additional characterizations or descriptions of leadership. Leadership characteristics, structures, styles codes were added in this theme to capture these instances. A general, or unspecified code, was included to capture general references to "leadership" in which no specific aspect of leadership was clear. The results of the leadership characterization coding by question are included as Figure 4-11.

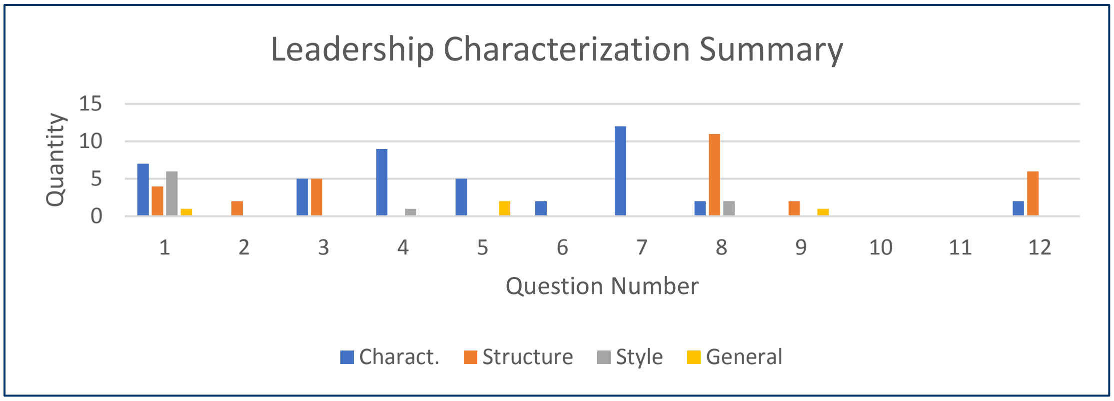


Figure 4-11. Summary of the leadership characterizations or descriptions by category: characteristic, structure, style, general (or uncharacterized).

Characteristics and structure are the most common leadership categories mentioned during the interviews. This correlates to the three questions that address the development of leadership structures and roles and the two questions related to characteristics of effective and ineffective leaders. Structure is also central to the discussion of informal leadership roles in question eight. The remaining discussion of characteristics and structure in question twelve addresses the possibility of developing leaders by encouraging and educating students on the importance of informal leadership within engineering organizations.

The first question is the most inclusive of the unique leadership categories. This possibly corresponds to the participants addressing their general thoughts on leadership during the opening question. Ericsson, Heinemann and Wright address leadership style by discussing the degree of participation and the range of styles from autocratic to collaborative. These instructors discuss these approaches to leadership while the teams are selecting leaders and developing team structures and procedures. They later address these styles when elaborating on the characteristics of effective leaders.

4.4.2.4 Context

The context theme includes the codes: project, product, field, and team. The results of context coding are summarized in Figure 4-12. This theme provides insight into the context that a faculty member uses to respond to specific questions. For example, is success for a leader or team defined by the product outcome or in terms of the project? It could also manifest the impacts of the context on the response, for example, what are the differences in leadership structures in industry and student teams?

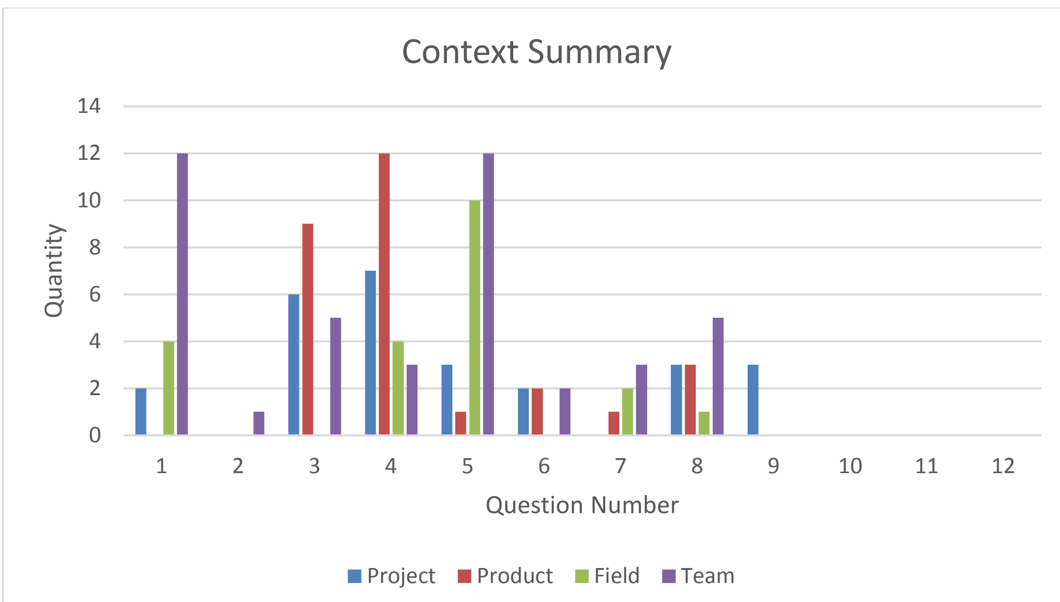


Figure 4-12. Summary of context theme coding: project, product, field, and team

"Team" is the most common code, particularly in question one addressing the team's leadership structure, and question five concerning leadership development. Leadership structures are described in relation to the team, however, Dr. Whittle describes structures in terms of the subassemblies that make up the product. Leadership development is also often described in terms of the team. Dr. Whittle emphasized the significance of team design experiences to developing leadership skills. He also emphasized the value of working in teams composed of multidisciplinary representatives to developing teamwork and leadership skills.

Faculty described their perceptions of effective leadership characteristics in a variety of contexts. As discussed in 4.3.4.4, effective communication skills are valuable to leaders. Dr. Ford describes this communication skill as the ability to communicate technical details concerning the product to a variety of audiences. Student perception of effective leadership is often tied to the success of the product, while the faculty expressed the value of developing teamwork skills and learning how to design.

4.4.3 Latent Semantic Analysis

Latent Semantic Analysis (LSA) is a mathematical tool that may be used to analyze text and quantify similarity between the texts [124–127]. A LSA application was used to analyze the five transcribed interviews for similarity[3]. The matrix comparison tool was applied using the general reading up to the first year of college corpus and the maximum number of factors available (300). This application compares the texts and provides a cosine similarity in matrix format. The results are provided in Figure 4-13.

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[3] "Latent Semantic Analysis at Colorado University Boulder" [Online]. Available: http://lsa.colorado.edu/. [Accessed: 12-Nov-2018].

Document	*Erickson*	*Ford*	*Heinemann*	*Whittle*	*Roebling*
Erickson	1	0.87	**1.00**	0.87	**1.00**
Ford		1	0.87	0.99	0.87
Heinemann			1	0.87	**1.00**
Whittle				1	0.87
Roebling					1

Figure 4-13. Latent Semantic Analysis matrix comparison results for five transcribed interviews.

The resulting matrix displays the pairwise comparison of the transcriptions of each participant's interview responses. Diagonal values are all one, and only the upper triangular values are provided since the matrix is symmetric. The aggregate texts all demonstrate relatively high similarity. This is not unexpected due to the common questions and background of participants as instructors. Highest similarities relate three interview transcriptions. Each of these instructors has a background in design research, suggesting that this similarity in research background may be reflected in their responses. For example, each of these instructors also discussed leadership styles in their interview responses.

4.5 Findings and Conclusions

Interviews were conducted to address all three research questions: emergence, distribution, and composition. This section presents answers to the questions inferred from the interviews.

4.5.1 RQ 1: Emergence

Instructors detailed their teams' approach to developing leadership structures. Most faculty provided some guidance but left the identification of roles and selection of leaders to the teams; the teams established their structures within the first weeks of the projects. The formal structures generally remained consistent, although, some were encouraged to rotate roles during the early stages of the project. Student teams often pick their leaders based on limited familiarity and the willingness of members to volunteer—this can sometimes result in suboptimal selections and structures. The faculty perceived the critical traits and actions exhibited by the effective student leaders to include strong communication skills and the willingness to both provide direction and perform engineering tasks, or "get their hands dirty." Consideration was the most commonly addressed relational behavior acknowledged in faculty comments. Overconfidence, weak communication skills, and failure to provide feedback resulted in less effective student leaders.

4.5.2 RQ 2: Distribution

The faculty perception is that the distribution of leadership functions is not completely bounded by the formal leadership structures. A common theme in interview responses was that each student has opportunities to lead during the lifecycle of the project. These opportunities are often related to the technical skills needed at a given point in the project, and that in successful teams, informal leaders emerge to ensure that specific needs are filled. Informal leaders also perform leadership functions when designated leaders are not suited to perform those functions due to outside requirements or personal abilities.

Leadership development can occur for all members of the team since the projects are sufficiently challenging to allow all students to perform leadership functions and observe the effectiveness of other leaders (student and faculty).

4.5.3 RQ 3: Composition

Faculty often perform the primary tasks of composing the team such as member selection. The size of teams is established based on the scope and complexity of the project, with larger teams often being formed to address products with multiple sub-assemblies or multi-functional requirements. This can necessitate that IPT leaders be established to lead efforts within the larger system of teams. The resulting structures are clearly more complex and provide opportunities to develop leadership skills within multi-disciplinary teams.

4.6 Summary

Chapter Four described the interviews conducted and analyzed to identify faculty perceptions on leadership and the formation and composition of teams. The interviews contributed to research questions one through three. Early insights assisted with the formulation of later study methods and the overall research approach. Chapter Five will address case studies that have been performed to analyze leadership behaviors in student teams. Figure 4-14 depicts the current progress and location in the dissertation.

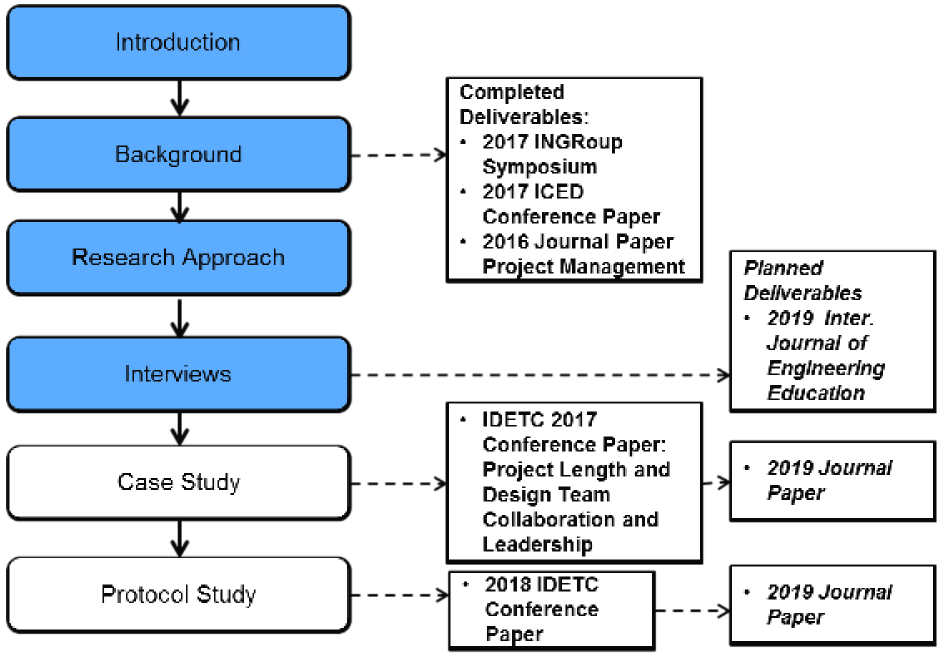

Figure 4-14. Dissertation Roadmap

CHAPTER FIVE: ENGINEERING DESIGN TEAM LEADERSHIP CASE STUDIES

The case study is a research method that provides empirical data to support analysis and understanding of a case consisting of an individual, a group, or an event. The defining characteristic of a case study is that it allows the study of an actual group or event when and where it naturally occurs [128–130]. It is a planned or designed study that results in the collection and analysis of empirical data [131]. Figure 5-1 depicts the case study within the overall research methodology. Each of the three research questions is addressed in the case studies.

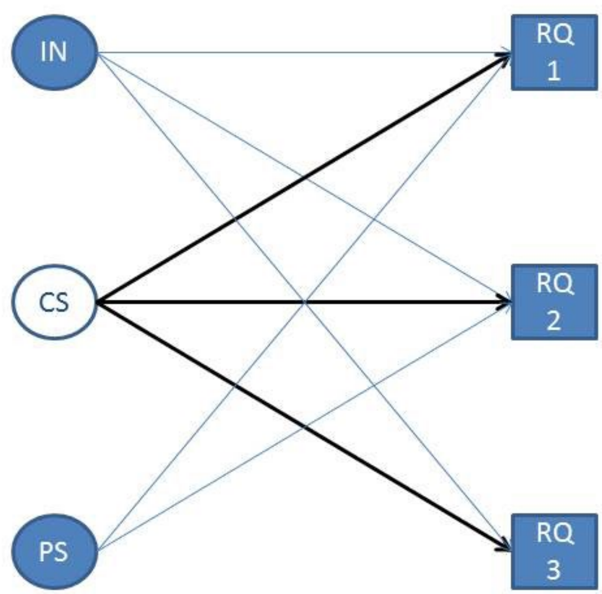

Figure 5-1. Graph showing the case study within the overall research approach

Significantly, the case study overcomes one of the primary shortcomings of laboratory research by allowing it to be studied within its full and natural context.

Laboratory studies often provide an unnatural or even sterile environment that may not elicit the same behavior as would be encountered in a field study. In this way, case study research enables the researcher to identify challenges and trends within this natural context. It also provides data that can be analyzed to identify these trends or problems in a systematic way [52,131]. Disadvantages result from the same rich context that provides the benefits of the study. Several of the advantages and disadvantages of the case study methodology are listed in Table 5-1. The challenges with isolating variables will be mitigated by the protocol studies presented in Chapter Six.

Table 5-1. Advantages and disadvantages of case study research approach

Advantages	Disadvantages
• Natural context for scenario studied [128] • Decreased concern with eliminating confounding variables [132] • Good at identifying challenges and underlying phenomenon in a specific case [130]	• Challenge to isolate variables • Long time to plan and conduct the study compared to laboratory experiments [128] • Difficult to draw generalizable conclusions [130]

5.1.1 Case study for Engineering Design Teams

The use of case studies for engineering design research has been well established and often applies multiple research methods to triangulate results [128]. Case studies using senior undergraduate design students as novice engineers have been used to evaluate tools and methods prior to use by industry. Project documentation and interviews may be used to explore theories in specifically selected cases without impacting the participants [133]. Using these and other methods, case studies have been used to explore topics ranging from design and sketching to process modeling and requirements development [9,134–137].

5.1.2 Purpose

The case studies were designed to investigate research questions one, two, and three (Table 5-2). The first case study (5.2) provided initial insights into leadership and communication in Capstone teams and manifested additional research requirements. These requirements were pursued during both interviews (Chapter Four) and the follow-on case studies. The second case study (5.3) examined leadership and communication structures in a two-semester capstone team. The final case study (5.4) targeted the emergence of leadership by establishing the leadership structure at multiple points in the life of the project.

Table 5-2. Research questions addressed by the case study

RQ 1: How does leadership emerge in engineering design teams?
RQ 2: How are leadership functions distributed within the engineering design team?
RQ 3: How does composition (size, organization) impact leadership structure (position and functional distribution) in engineering design teams?

5.2 ME 4020 and Aerospace [43]

A preliminary case study was performed on student design projects of one and two semester duration to begin to assess the impact of project length on leadership and communication within the design team [43]. The case study allows the exploration of research questions within the context of actual design teams and is best used to answer questions such as why and how phenomena occur within that given context. This topic was selected based on the experiences of the research team and the composition of current capstone design projects. A desired outcome of the preliminary study was the development of concepts and hypotheses for future research.

5.2.1 Objective

The temporal aspects of a design team are often defined within the limits of the project length. The project length and the team member's perceptions of time impact the team's objectives, processes and activities, and how they are mapped to time [138]. The activities affected could include communication and leadership behaviors.

Research that aims to identify the effect that project length plays on collaboration is something that has not been studied in depth and merits pursuit. Improved understanding of the impacts that project length has on a design project could be applied in both industry and academic settings. Understanding of these temporal characteristics' impacts on communication and leadership behaviors could enable the development of design team interventions and management techniques. They could also be applied in the development and management of capstone design team experiences.

5.2.2 Communication in Design Teams

Communication is a fundamental component of the collaborative design process. The mode of communication may be driven by the information that needs to be conveyed or by the distribution of the team members and the information involved. Distribution of team members and information may be a function of geography and transportation barriers. It may also be related to organizational boundaries between members of the team and may be impacted by the temporal alignment of team members and their communication exchanges [2,26].

Communication can be described or quantified by its frequency and its duration. These measures can be used to understand the quantity of communication that occurs and its patterns. However, the effectiveness of the communication is also impacted by the proficiency of team members in communicating and in using the technology required for communication of design information [2].

Communication roles have been investigated within architecture design teams. These roles include communication between team members, boundary spanning roles, and outside of the design teams [139]. The influence of organizational structure on design teams and their effectiveness has also been investigated [140]. Additional research establishes relationships between communication structures, leadership structures, and trust structures [27].

5.2.3 Multi-team Systems

While teams may function independently, they may also serve within systems of teams as discussed in 2.4. This system of teams is considered a multi-team system (MTS) when there is more than one interdependent team working to achieve a common goal. This relationship can exist within engineering constructs of complex products or in concurrent engineering. In an MTS, the interactions and relationships between component teams often share equal significance with the collaboration within component teams [58].

5.2.4 Temporal aspects

All design problems and teams operate within a temporal framework, just as they work within the context of their team composition and within a geographic setting or distribution. This framework encompasses the bounds of both project start and end dates and the cyclical framework of recurring events such as meetings. Time frameworks can be described in terms of conception of time, mapping activities to time, and how actors (in this case designers) relate to time [138].

Student design teams and industry teams are both affected by time. Project durations are often determined or influenced by customer requirements or project complexity. In academic environments they generally conform to the academic calendar (semesters, trimesters). Capstone design projects have varied lengths, generally ranging from one-semester to one-year, although there are courses outside of those parameters. This length impacts the scope, objectives and final products of the student design teams [141]. Teams in other contexts are also impacted by time frame. Complex teams, such as large product design teams, may operate on distinct timeframes and with differing conceptions of time and routines. This could require synchronization of team schedules [142]. This study aims to better understand the impact of project length on the communication and leadership behaviors of design teams.

5.2.5 Study approach

The case study was chosen to examine leadership and communication in design teams because it provides a holistic view of the teams in their natural context [128–130]. It is not practical to replicate the design environment for a six-month to one-year duration in a laboratory although independent activities were replicated and observed in the protocol study (Chapter Six). Case studies have been performed in the past to study capstone design courses and teams composed of "novice engineers" [134,135,137,143–145]. The students in the study are within months of entering the workforce as degreed engineers. Case studies enable the study of design methods within their natural context to increase understanding, develop theories, validate methods, and develop future research questions [128].

Upon determining that a case study was the best method, the specific cases to be studied were identified. This decision was based on several factors: time constraints, access, and availability. Therefore, cases identified were the senior design projects that were occurring at Clemson during the time of the study. Clemson's Capstone senior design course consists of second semester mechanical engineering seniors who are solving a design problem for companies. These students are close to graduation and engineering practice, making their knowledge of engineering similar to that of a novice engineer in industry.

Throughout this class, students focus on developing a solution and prototype which they can present to the company at the end of the semester. In order to ensure that the students are staying on track, they have weekly design reviews overseen by a faculty coach and a graduate advisor. At the time of this study, there was a two-semester senior design project as well as several one-semester projects underway. Because the main variable in the study was project length, the cases that were chosen were the two-semester project and two of the one-semester projects.

Design project teams within the one-semester projects possessed the characteristics of a traditional small project team working on one distinct project. The project team was able to complete their project entirely within their single team. Although they were required to interact with customers and project advisors, the scope of their project was designed to be completed by a single team of approximately four members.

The two-semester teams existed within a more complex construct. These projects were performed by a team of twelve members, subdivided into three sub-teams. Each team was responsible for one sub-assembly of the overall design. The sub-teams were each located in geographically dispersed universities. This construct could potentially be explored as a system of teams, as each of the sub-teams is dispersed geographically and organizationally, although they are working on a single project. The dynamics of these systems can be considered by the number of sub-teams, size of the project team, organizational diversity, dispersion, and additional attributes [6].

To collect data in the various cases a survey was used. The questions are provided in Table 5-3. A survey was chosen as the best method of data collection for several reasons. One reason was because of the time constraint. Compared to other data collection methods such as document analysis and interviews, surveys take significantly less time and do not require the researcher to be present for administration. In the case of interviews, it can be difficult to get someone to take the time to sit down and discuss their opinions if their participation is not required, whereas with a survey it is significantly easier to collect a sufficient data size. The survey instrument parallels the collaborative design research instrument previously used to explore leadership and communication within undergraduate student design teams [96].

Table 5-3. Preliminary study leadership and communication questionnaire [43]

1.	Does your group have an established leader?	Yes No
2.	Was your group leader:	A) In scheduled meetings of entire project team? B) In scheduled meetings of sub-group? C) Assumed (no conscious selection)
3.	What types of decisions does the group make by vote?	
4.	What types of decision are made by consensus (agreement by all)?	
5.	What types of decision are made by the group's leader?	
6.	On average, over the last month, how often did you communicate with other team members:	A) In scheduled meetings of entire project team? B) In scheduled meetings of sub-group? C) Scheduled one-on-one meetings? D)Non-scheduled, impromptu, meetings?
7.	When you communicate, how long does the discussion last:	A) In scheduled meetings of entire project team? B) In scheduled meetings of sub-group? C) Scheduled one-on-one meetings? D) Non-scheduled, impromptu, meetings?
8.	How often (in the last month) were there misunderstandings in communication with team members:	A) During in-person (collocated) meetings? B) During technology assisted meetings (members at different locations)?
9.	Are design problems solved individually or as a group?	
10.	How accepting are your group members to your opinion on problems (mark on the line where appropriate)?	A) Very Unaccepting B) Unaccepting C) Indifferent D) Accepting E) Very Accepting
11.	Have you ever worked with one or more of your group members in a school-based activity? If so what (e.g. group project, lab, etc.):	A) Yes B) No
12.	Do you ever spend time with any of your group members in social activities? If so how often?	A) Yes B) No
If you have any further comments or want to elaborate on an answer, please feel free to do so below.		

Because the amount of collaboration in a group is complex, it is necessary to define what aspects of it are important. A list of various metrics which can be used to describe collaboration is shown in [5]. However, as many of these metrics are outside the scope of this problem only seven have been chosen. The metrics which are the focus of the surveys are team leadership style, communication frequency, communication duration, communication reliability, past relations, team building activities, and perceived level of criticality.

5.2.6 Study results

Surveys were distributed to 24 students who were members of senior design project teams with duration of one semester. The response rate for these students was 96%. The available quantity of students on year-long design teams was 12. The survey response rate was 42%.

5.2.6.1 Leadership and Decision Making

Corporations generally assign formal leadership for programs and projects and design teams. Other leadership roles are created by functional positions or informal leadership responsibilities. Student design teams are often less formally structured. While some faculty may assign specific leadership roles, this responsibility is often delegated to the student team members. Students may formally select leaders by vote, by consensus of all members, or leadership may be assumed out of necessity by one member.

The faculty did not assign leadership roles in the case of any of the projects considered in this case study. Clemson teams within the two-semester project all selected a leader by vote. Each of these teams was a sub-team within an overall project team consisting of students from three universities. The decision-making methods reported by these teams are summarized in Table 5-4. The leader primarily made administrative decisions, although some members reported some "last minute design changes" were made by the leader. Administrative decisions include topics such as scheduling meeting details. Some administrative decisions were decided by vote, but most design decisions were made by consensus. Design decisions are decisions that directly impact the design or prototype.

Table 5-4. Decision methods and corresponding decision types for student projects based on preponderant survey responses (Questions 3-5) [43]

Decision Method	1 Semester	1 Academic Year
Vote	Design decisions	Administrative
Consensus	Design decisions	Design decisions
Leader's Decision	Administrative	Administrative Time-sensitive design changes

The one-semester project teams did not have this homogeneity in leadership selection. For these projects, 56% of the participants reported having selected their leader by vote. The remaining respondents did not make a formal selection, but rather, assumed their leader. Assumed leadership is defined for this study as a leadership selection that is not explicitly made, but rather, the leader takes on the role for expedience-- and the leader's role is accepted by the group.

5.2.6.2 Communication.

Project teams were asked to report on the frequency and duration of team meetings and discussions. These discussions were distinguished as whole project team, sub-team, one-to-one scheduled, and impromptu discussions. Two-semester project team members and one-semester team members reported a similar frequency of meetings in most categories. The one-semester project teams did report approximately 26 discussions per month, while the one-year teams reported 20 per month.

The one-semester, whole team meetings and sub team-meetings were reported to last approximately thirty minutes longer than those of the one-year team. Overall, the summation of discussion times for one-semester teams was approximately ten hours more per month. One notable exception is that scheduled one-on-one meetings lasted approximately one hour longer per discussion on the two-semester teams. These meetings occurred at approximately the same frequency. The survey responses are summarized in Table 5-5.

Table 5-5. Communication frequency (per month) and duration (hours per meeting) for undergraduate project teams in study [43]

Discussion Size	One-semester teams		Year-long teams	
	Frequency (Per month)	Duration (hours/event)	Frequency (Per month)	Duration (hours/event)
Project team	10	1.5	8	1.1
Sub-team	9	1.3	4	0.7
One-to-one	4	0.4	5	1.4
Unscheduled	4	0.6	4	0.5
Total	27	1.13	21	0.98

This could be related to the maturity of the project teams, although this cannot be determined by this case study. The teams had been working together for a full-semester longer than the shorter duration team, and as a result, the efficiency of team meetings may be increased. The efficiency of team meetings was not specifically studied in this case study; however, future studies could be performed to investigate the relationship between project length and design team meeting efficiency.

However, it is also possible that the lower frequency and duration of meetings is related to the geographic dispersion and the mode of communication. The one-semester teams could hold their meetings in person in a single location in most instances. There were instances when team members were out of town and required to use telecommunications to interact, but, this was not their primary mode of communication. The two-semester teams were required to hold the majority of their meetings by video teleconference (Skype). The added complexity of scheduling communications, and the reliance on technology assisted meetings, could affect frequency and duration of meetings. It could also force the two-semester teams to streamline their communications and increase the efficiency of meetings.

One clear departure from this trend is the frequency of one-on-one scheduled meetings. Two-semester team members reported holding more, and longer, one-on-one meetings. This could be due to the ease in scheduling single telephone or Skype communication vice scheduling large group meetings between the universities.

Related to this increase in technology reliance is an increase in short-term misunderstandings in communication. Those members of the two-semester teams reported more misunderstandings in technology assisted meetings than at in-person meetings. Their reported rate of misunderstandings at in-person meetings was consistent with one-semester teams. This is consistent with expectations due to the increased number of dispersed meetings.

5.2.6.3 Group Dynamics.

Project team members for both types of project reported similar rates of acceptance. Respondents to the survey reported an average acceptance rate of approximately 4.3, with four corresponding to a response of accepting to my ideas and five corresponding to a response of very accepting to my ideas. The one-semester team members were much more likely to have worked together on a school activity before the beginning of capstone design projects. They were also more likely to socialize together.

There could be many influences on the likelihood of the project members working together previously or on their social interactions. The most obvious factor is location of project team members. Team members from different universities would be extremely unlikely to have worked together previously. This does not entirely account for the differences, since members of the sub-team would be from the same institution. This dispersion also clearly impacts the ability of team members to socialize. Teams on the two-semester project would be unable to socialize (in-person) unless they are meeting at a single location to work on the project. Respondents from the two-semester team did indicate that they had dinner together during these team meetings at a single location. Additional investigation is needed to determine if team member location and project length each effect group dynamics individually or if there is a correlated effect.

5.2.6.4 Leadership Complexity

This added complexity requires members of sub-teams to function both within their component team, and within the larger system of teams that comprise the project team to integrate component assemblies into one mechanical system. This complexity could also influence the decision of the two-semester project teams to select their leaders by vote, although it could also be influenced by project faculty or sponsor preference. However, this additional complexity would make it difficult to function efficiently without an explicitly selected leader.

Group decision making methods exhibited some differences. It is not possible to demonstrate causality based on the case study, however, project dynamics are likely influencing factors. While the semester-long teams primarily voted on design decisions, the two-semester teams primarily voted on both design and administrative decisions. These administrative items included decisions on where to meet to build components or integrate components of the assembly. The meeting times and places involved travel for project team members, so these decisions would have higher implications for the team than on a project where all members are co-located. It is also likely that decisions could be quickly made by the leader, with low impact when all team members have similar design review times and meeting locations.

Some team members (2 of 5) for the two-semester project reported that the leader was required to make some time sensitive, last-minute, design change decisions. This could be necessitated by the need to integrate assemblies and to modify designs based on the resulting performance of the overall system.

5.2.6.5 Summary and future work

There are clear distinctions in the dynamics of the project teams considered in this case study. The one-semester teams worked in small single unit teams. They were also co-located and composed of members from the same university. One-year teams were components of larger project teams, working to design at least one sub-assembly of a major device, and to integrate that with the overall project team. The differences in the structural complexity of the teams could have definite impact on communication, leadership, and cohesion within the project teams.

One-semester teams communicated more frequently as a project team, although year-long teams held more one-on-one communications. Leadership structures on the one-year team were more explicit, than the one semester team. The more explicit structure is possibly a result of the increased complexity of the project team structure.

Distinctions can be identified between teams, it is difficult to establish causality within the scope of this case study. There are numerous complexity factors that are related to the projects as well as a low sample size. Leadership roles could only be explored based on the one-time survey responses. There are opportunities for future work to establish the impact of leadership structures and team composition on project effectiveness and creativity. Future work opportunities include further study of project length on design team behaviors with increased sample size. Additionally, future work can be performed to identify the relationship between project length and team meeting efficiency. Future work focusing on the desperation of the team members could be performed to validate whether these results are due to the differences in project length or the differences in the geographical dispersions of these teams. They also include investigation of behaviors with consideration for their direction and timing in a laboratory environment.

5.3 Spring 2017: Aerospace Network Analysis

The preliminary study indicated that multi-team systems may have more complex leadership relationships than the smaller design teams. A second case was conducted to explore the leadership networks and the distribution of leadership functions within these systems. The participants for this case were a one-year project team of similar composition as the preliminary study. The team was required to design, build, and test an unmanned aerial system (UAS) during the course [43].

5.3.1 Survey development

The survey instrument must establish the leader – follower or leader – member relationship of the respondent to each team member. This will enable the study of the leadership networks and communication networks within the case team. The survey instrument is based on questions developed and applied in a previous study of undergraduate [93]. It is also consistent with network leadership measures in studies with management student participants [146].

The questions will establish each team member's reliance on other team members for the top tier of leadership behaviors by phase: transition behaviors, action behaviors, and relational behaviors. This is representative of the perceived leadership network for the team [93]. The questions are modified from the original format to limit the time required per survey while still achieving the desired level of granularity in the data. The original questions establish responses from the individual behaviors within each top tier or phase. However, the original survey was intended for teams of four to six members. Given a team of ten members, the time to complete each survey becomes prohibitive. Initial responses establish that the required survey time is approximately nine to ten minutes, or one minute per team member evaluated. The survey questions are included as Table 5-6.

Table 5-6. Case study survey instrument

To what degree do you rely on John for:	5-Frequently if not always 4-Fairly often 3-Once in a while 2-Sometimes 1-Never
(a) Planning: identifying main tasks, setting goals, developing performance strategies for the team?	① ② ③ ④ ⑤
(b) Team action activities: monitor goal progress, coordinating work efforts, and providing assistance when needed with tasks?	① ② ③ ④ ⑤
(c) Team relations: dealing with personal conflicts, encouraging team members, keeping emotional balance?	① ② ③ ④ ⑤
How often do you interact with John:	5-Frequently if not always 4-Fairly often 3-Once in a while 2-Sometimes 1-Never
(a) Face to Face	① ② ③ ④ ⑤
(b) Using text and written communications	① ② ③ ④ ⑤
(c) Using audio or visual communication (telephone, Skype…)	① ② ③ ④ ⑤

Transition activities generally involve assessing previous actions and preparing for future actions. Action activities are directly related to the team's task work, while relational functions include interpersonal behaviors such as consideration [81]. This is representative of the perceived leadership network for the team [93]. Initial responses establish that the required survey time is approximately nine to ten minutes, or one minute

per team member evaluated. Each question is answered with a value of one through five, with five being the highest frequency of reliance on the member for leadership. The responses for questions one through three provide a composite leadership response for the three phases of transition, action, and interpersonal leadership behaviors. Rather than a peer evaluation, the survey is merely an evaluation of the performance of specific behaviors with whom the team interact during the specified time.

Initial survey analysis explores the leadership network based on survey responses. The survey responses are exported from Qualtrics to Microsoft Excel. An Excel spreadsheet is used to develop an adjacency matrix that establishes the perceived leadership network for the desired category. The adjacency matrix can then be used as input data for Net Draw [147]. Figure 5-2 is a matrix representing responses to survey questions one through three. Each question is answered with a value of one through five, with five being the highest reliance on the member for leadership. The responses for questions one through three provide a composite leadership response for the three phases of transition, action, and interpersonal leadership behaviors. Participants are clearly instructed that the survey is not a peer evaluation: they are providing their evaluation of the performance of specific behaviors by team members they interacted with during the specified time.

OVERALL LEADERSHIP (L1+L2+L3)

	1	2	3	4	5	6	7	8	9	10
1	0	11	12	8	8	5	7	8	5	10
2	10	0	11	6	8	3	4	4	5	10
3	15	15	0	7	8	9	0	0	5	12
4	11	11	11	0	9	6	9	6	6	10
5	9	12	12	0	0	0	0	0	0	12
6	11	11	10	9	9	0	9	9	10	11
7	12	12	12	12	11	12	0	12	0	13
8	11	9	9	10	0	9	9	0	0	12
9	13	9	9	8	6	7	6	6	0	12
10	11	12	10	4	6	10	4	5	8	0
AVERAGE	11.4	11	11	7	7	6.8	5.3	5.6	4.3	11.3

Figure 5-2. Representative matrix for leadership intra-MTS

5.3.1.1 Leadership Network Graph

The adjacency matrix is converted to a network representation of the entire design team in Figure 5-3. In the graph, each member is represented as a node. Each instance where the total combined leadership score from one member to another is nine or greater is represented as a directional tie between the two nodes. The tie is directional, and the arrow represents the direction of reliance. For instance, there is a tie between nodes nine and ten with the arrow pointing toward ten. This indicates that nine is relying on ten for leadership at a level that qualifies for a tie in the graph. The inverse is not true. Further analysis is required to establish networks within sub teams and between sub-teams.

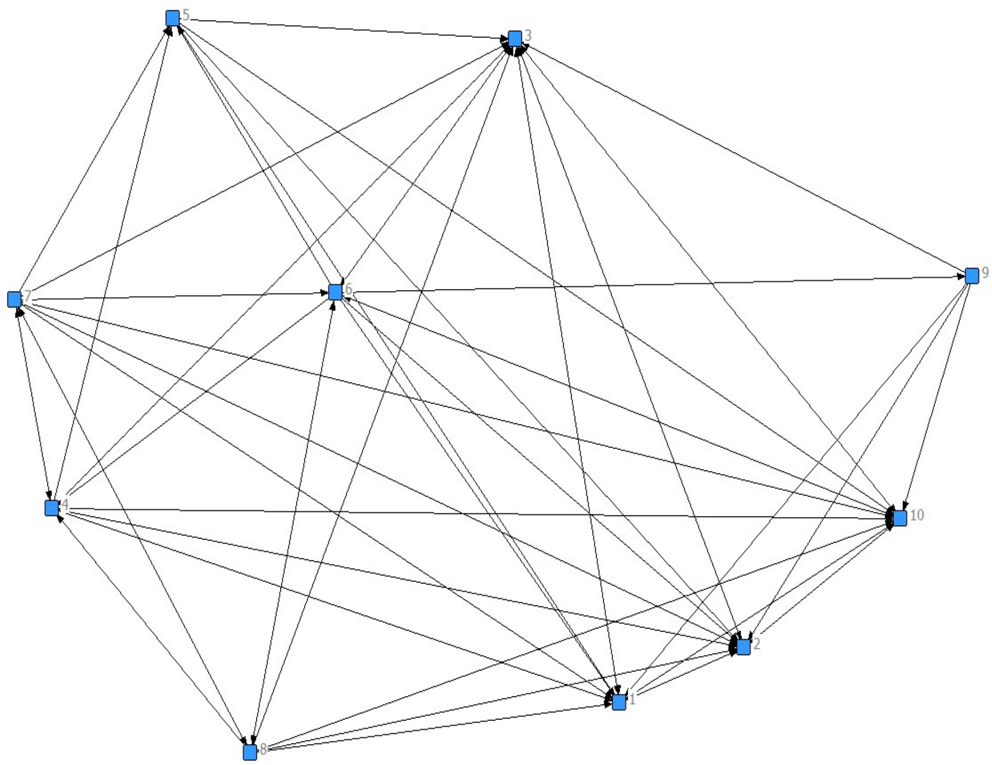

Figure 5-3. Network representation of leadership network

5.3.1.2 Communication Networks

Communication networks will be established and represented in the same manner as the leadership network. Networks can be delineated by communication mode as determined by the survey design and responses. It is expected that the communication networks will be related to the leadership networks.

5.3.2 Establishing Leadership and Communications Networks

Social network analysis has been used to study the dynamics within populations, organizations, and teams [147]. Networks are established based on known associations between people and specified activities relating the network's members, such as common memberships or communication [148]. Leadership can be explored directly as one of these network relationships for purposes of elucidating the influence and distribution of leadership [64].

A variety of techniques and data sources are used to establish these networks, which once established are used to understand the interactions of members. In this study, Dependency Structure Matrices, DSMs, are used to model the leadership and communication networks within a capstone design team to better understand where leadership functions are actually performed within teams. This increased understanding will form the basis for network comparisons and serve to inform future intervention development. The DSMs are developed and analyzed using the process adapted from the basic approach in [149,150]. Iterations of the process may be used to collect multiple samples or adjust the study population.

- The first step is to identify the subject system boundaries. Even the simplest capstone team can have multiple unique boundaries. The team members alone may comprise the system, or it may be expanded to include the faculty coach and student advisors. It may also include sponsors and suppliers, or peer teams working on the same design challenge. In this particular case, a capstone design team with ten members was identified as the system.

- The second step is to administer the survey instrument to the team members. The survey establishes the perception of the performance of specific leadership functions (transition, action, and interpersonal) between team members. It also establishes the reported frequency of communication in three different modes (face-to-face), text (email, messaging), and video conferencing.
- DSMs are then established from the survey responses indicating the perceived leadership and communication networks within the design team. Matrices are established for each leadership and communication category at each frequency level.
- In the final step, matrices are analyzed for social network analysis criteria and further for complexity comparison.

5.3.3 Team Composition and System Boundary

The case team is similar in composition to the one-year team in the preliminary study. The design team is a distributed team of ten senior design students, which were selected from three universities based on an algorithm with inputs of technical skills, motivation, social skills, and leadership skills [151]. The key features of the team and the collaborative environment using a previously established collaborative design framework are summarized in Table 5-7 [2].

Table 5-7. Study design team details

Taxon	Description
Team	10 designers
Distribution	3 universities (2 public, 1 private) Doctoral granting universities 15-30K undergraduates
Information	Information management within Sharepoint. Peer review and group permissions.
Communication	Video conferencing Group text messaging Email
Problem Nature	Variant (first exposure for many team members)
Design Approach	Systems engineering design process mandated (NASA Systems Engineering Handbook)

5.3.4 Communication

Communication is facilitated through a variety of modes given that this distributed construct and project information is maintained in a central web-based system. Multiple information technology systems are used in the project team's communication.

5.3.5 Problem Nature

The problem is a variant design. However, for most of the students, this is their first exposure to UAV design. This first exposure places the problem nature on a spectrum between novel and variant [29].

5.3.6 Distribution and temporal aspects

The team is distributed geographically as the members are located in three different states. The team is distributed organizationally. Team members are enrolled in three different universities. Due to the physical separation of the teams and the different time zones in their institutions, there is also a temporal distribution. The project is a one academic year project.

5.3.7 DSM Construction

The DSM representation of (a) the perceived leadership graph for transition phase tasks and (b) audio-visual communication (i.e. video conference) is shown in Figure 5-4. The nodes are indicated on the axes and the relations are indicated by the number "1" in a matrix cell, a format indicating the dyadic relationships between designers [152]. In this matrix, each of the row labels indicates a source node and each column indicates the sink node.

(a) Designer (Sink)

Designer (Source)	1	2	3	4	5	6	7	8	9	10
1		1	0	0	0	0	0	0	0	0
2	1		0	0	0	0	0	0	0	0
3	0	0		0	0	0	0	0	0	0
4	0	0	0		0	0	0	0	0	0
5	0	0	0	0		0	0	0	0	0
6	1	0	0	0	0		0	0	0	1
7	0	0	0	0	0	0		0	0	1
8	1	0	0	0	0	0	0		0	0
9	0	0	0	0	0	0	0	0		1
10	0	0	0	0	0	0	0	0	0	

(b) Designer (Sink)

Designer (Source)	1	2	3	4	5	6	7	8	9	10
1		1	1	1	1	0	0	0	0	1
2	0		0	0	0	0	0	0	0	0
3	0	0		0	0	0	0	0	0	1
4	0	0	0		0	0	0	0	0	0
5	0	0	0	0		0	0	0	0	0
6	0	0	0	0	1		0	1	0	0
7	0	1	1	0	0	0		0	0	1
8	0	0	0	0	0	0	0		0	0
9	0	0	0	0	0	0	0	0		0
10	0	0	0	0	0	0	0	0	0	

Figure 5-4. DSM for the case study for (a) transition leadership functions and (b) audio-visual electronic communication (video conference) frequently if not always between designers.

The relationship is depicted in the DSM if the survey response indicates a frequency of reliance at or above the level specified. In this example, the number "1" in position (2,1) represents that designer two relies on designer one "frequently if not always" for transitional tasks such as planning, setting team goals, and developing strategies. The number “1” in the (1,2) position depicts designer 2’s reliance on designer 1 for the same function. The relations reflect the survey responses of the designers and are directional and of equal magnitude. The disconnect of nodes three, four, and to the other designers in this DSM indicates a weak connection of the network at this particular threshold and function [153].

Eighteen DSMs are constructed representing the three leadership functions and three communications modes at three distinct frequency levels. An additional 6 matrices are constructed for overall (summed) leadership and communication thresholds. The numbering scheme for the leadership and communication DSM’s is provided as Figure 5-5.

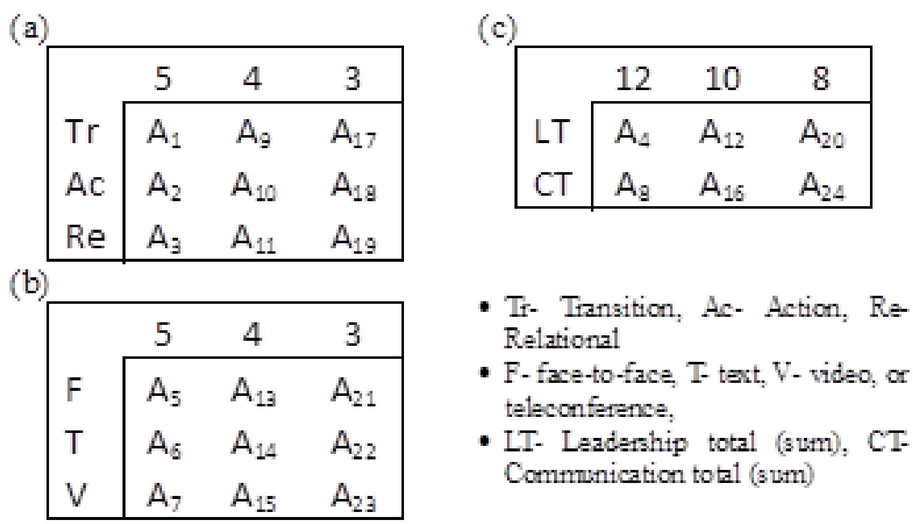

Figure 5-5. DSM numbering scheme for leadership and communications matrices to include: (a) leadership and (b) communication at discreet frequencies; (c) overall leadership and communication.

Network Analysis

Network analysis tools were used to explore the leadership and communications networks modeled with the DSMs with size and density first explored as indications of the distribution of specific functions. The overall complexity was then examined using a process previously published to analyze multi-dimensional DSMs [154].

5.3.8 Density and saturation

For the networks established as discussed, size is the initial indicator of the amount of involvement in the leadership network. The number of nodes with a connection at or above the specified frequency level indicates the number of members perceived as engaged in a given activity or function at or above the specified frequency level. For example, in Figure 5-4, seven out of ten nodes are either a source or sink for transition leadership functions. The frequency level at which all ten designers are represented as connected to the graph is indicated in Figure 5-6. The number of connections quantifies the number of paths that communication or leadership functions are occurring at or above a specified frequency with any relationship counted as uni-directional. In the leadership graph used as an example Figure 5-4 the relationship from designer two to designer 1 is counted as a single relationship, while that from designer 1 to designer 2 is a second and distinct relationship. Seven relationships are charted in the given graph.

The density of the network is the percentage of possible relations that exist in the graph [147,155,156]. The representation of the graph density in the matrix form is simply the number of cells populated with a non-zero value divided by the number of possible cells [157]. As expressed in Equation (5.1), n is the total number of designers (10 for this example) and the density for the example is .08, or 8%.

$$Density = \frac{Edges}{P(n,2)} = \frac{Edges}{(n*(n-1))} \qquad (5.1)$$

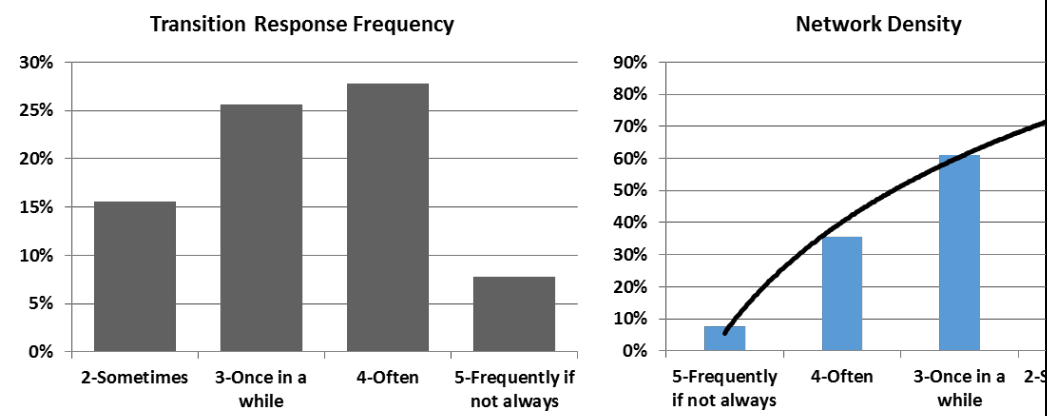

Figure 5-6 (a) Response frequency and (b) resulting network density for transition leadership functions.

The categorization of the responses for the transition phase leadership network is shown in Figure 5-6. Each bar in the chart indicates the relationships specifically attributed to the specified frequency of performing transition leadership functions as a percentage of all possible relationships. For example, approximately fifteen percent of possible relationships are attributed to responses of "sometimes" reliant on the indicated individual for transition leadership.

Each adjacency matrix, or DSM, depicts the relationships existing at or above a specified frequency. Also shown in Figure 5-6 is a representation of the density of relationships within each graph as the cumulative density of all responses at or below the threshold frequency for that network. "Frequently if not always (5)" is the highest threshold which has the sparsest graph as a result. “Often (4)” holds all relationships that are perceived as occurring at least as frequently as “often” which is the sum of all “4” and “5” responses. “Sometimes (2)” is the sum of all existing relationships in this category. A response of “never (1)” is not counted as this signifies the absence of a relationship for this category. As a result, the density at this threshold is less than 100 percent [153].

The density for all three phases of leadership functions is also shown in Figure 5-7, which permits the inference of the number of observations in terms of a side-by-side comparison. The density of relations for relational leadership was perceived as lower at every threshold frequency. Transition and action function densities were approximately equivalent at threshold frequencies of “sometimes” and “frequently if not always”. Although the number of designers perceived to perform these functions was equal at these thresholds, the action density was higher at the intermediate frequencies with values of 3 and 4. Thus a higher percentage of ties were due to the lower value of 2 in the transitional graphs.

Note also the communication density graph represented in Figure 5-7 in which both the text and audio-visual communication follow similar distribution curves. The densities for all face-to-face communications are lower than that for electronic text communication or audio-visual communication forms such as teleconferencing. Note the highest density for face-to-face communications at 58%, which is expected due to the distribution of the team members. During this phase of the project, geographic distances kept the entire team from meeting for manufacturing purposes, although a smaller subset was able to do so at low frequencies.

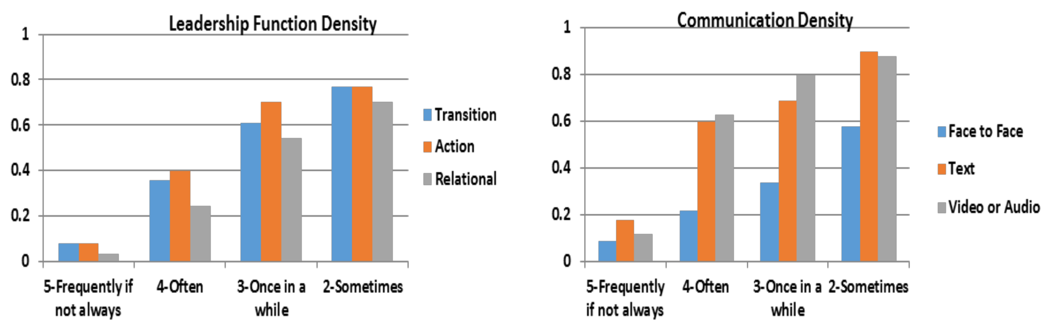

Figure 5-7. Leadership function and communication networks' density.

5.3.9 Graph Complexity Comparison

Each of the metrics listed described above represents a means to quantify the complexity of the network of designers in the context of leadership and communication functions and modes. Each metric provides insight into the ability of leadership or communication to enable the flow of influence and information respectively within the design team [64,157,158].

Complexity has been proposed as a method to compare graphs in which the complexity vectors are used for a more holistic comparison of the network complexity [156]. Each of the vector's terms measures the size, inter-connection, centrality, or decomposition of the network. The first of these metrics are described in 5.3.7: dimension or number of nodes and relations, and defined in [156].

These complexity metrics have been used to compare and predict engineering design multiple characteristics in engineering design research, specifically for comparing function models [154,159], and predicting assembly times [160] and defects in assembly processes [161]. Complexity vectors are calculated for each of the graphs using code also defined in [156]. The vectors are then normalized by dividing each component by the maximum value obtained from all graphs for the given characteristic to yield component vectors ranging in value from zero to one. A sample of traditional social network analysis metrics that form the basis of the complexity vectors is shown in Table 5-8, with a total of 29 metrics used in the comparison [148,153,157].

Table 5-8. Social network analysis metrics selected from complexity distance comparison.

		Tr 5	Act 5	Rel 5	CA 5	CB 5	CC 5
Dimension	Elements	7	7	4	6	9	9
	Relations	7	7	3	8	16	11
Connection	Max	1	1	1	2	3	1
	Mean	0.17	0.17	0.25	0.73	1.24	0.15
Flow Rate	Mean	0.29	0.31	0.38	0.56	0.93	0.30
	Density	0.04	0.04	0.13	0.07	0.06	0.03
Betweenness	Mean	0	0	0	0.33	3.78	0
	Density	0	0	0	0.04	0.24	0
Clustering Coefficient	Mean	0	0.10	0	0.33	0.36	0.10
	Density	0	0.01	0	0.04	0.02	0.01

5.3.10 Distance

After characterizing each network by its complexity vector, the vectors can be compared by the distance between the vectors. There are multiple approaches to calculating this distance. The cosine distance provides an indication of the angle between the two complexity vectors and has been selected to compare the complexity vectors for the 24 adjacency matrices considered [162]. The equation used to determine cosine distance is (5.2) [163].

$$\text{cosine } distance = \frac{A \cdot B}{\|A\|\|B\|} \qquad (5.2)$$

The cosine distance (5.2) will result in one for an angle of zero between the vectors and will result in zero for orthogonal vectors. One minus the cosine distance is used as an intuitive metric where larger magnitudes indicate greater dissimilarity is shown in Figure 5-8.

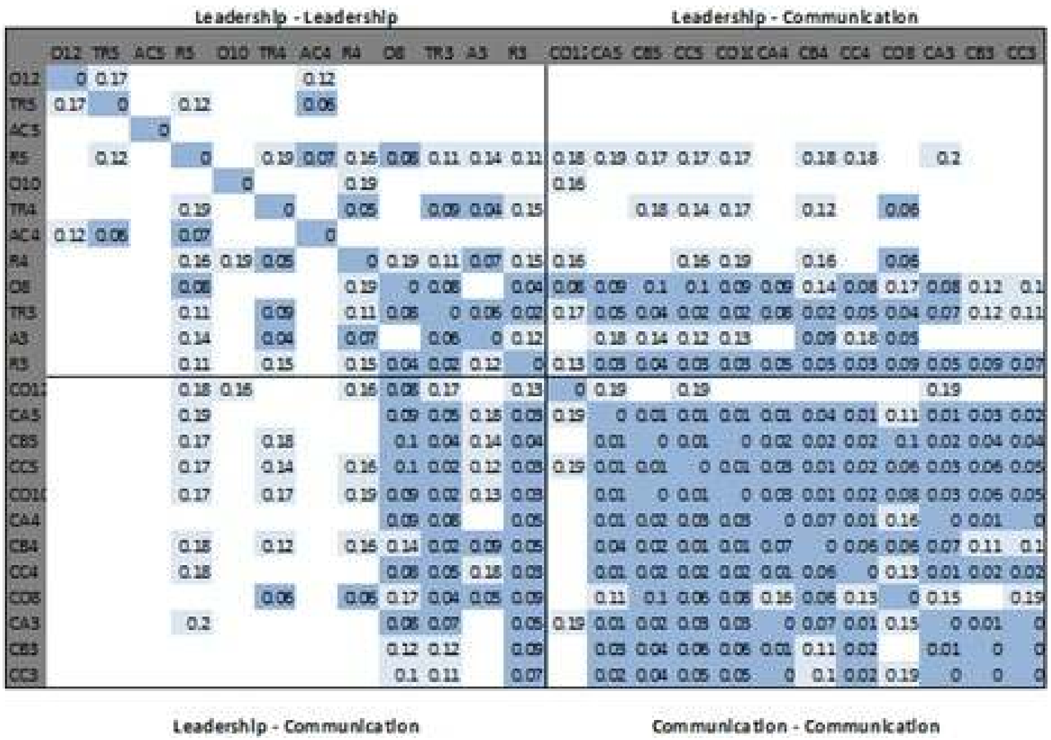

Figure 5-8. Complexity comparison based on cosine similarity (1-cosine distance).

The complexity comparison matrix, Figure 5-8, shows the distance between the complexity vectors of each graph. Distances range from zero to one, with zero indicating the absence of an angle between the two vectors. The matrix is formatted as a DSM, although with diagonal values of zero given the iteration as one minus cosine.

The DSM is considered as four quadrants based on the ordering of the graphs in Figure 5-5. The upper left quadrant is a comparison of perceived leadership complexity vectors to other perceived leadership complexity vectors. The lower right quadrant is populated by the distance between communication complexity vectors. The remaining two quadrants reflect comparisons between the leadership complexity vectors and communication complexity vectors.

5.3.11 Complexity Comparison Insights

The dark shaded cells in the comparison matrix indicate distances of less than 0.1 or approximately sixteen degrees, and the lightly shaded cells indicate relationships of less than 0.2. All other distances have been hidden for clarity.

The communication-to-communication distances exhibit low distances with the highest represented threshold of the combined communication frequencies exhibiting distances greater than 0.2. All other remaining comparisons between communications vectors are less than 0.2, however, indicating a similarity in their overall complexity vectors. The communications-to-leadership vector comparisons indicate the lowest distance between transition and relational vectors and most all categories of communication. The greater distance of the action leadership vectors to the communication vectors than the remaining phases, suggests a closer relationship between the communication networks and the transition and relational leadership networks.

5.3.12 Summary and Future Work

The perceptions of student designers were used to inform the creation of leadership and communications networks of peer roles in a capstone design project. The results used to elucidate the distribution of transition, action, and relational leadership functions in student engineering design teams. The size and density of leadership and communications networks indicate the degree of participation of individual designers. The maximum density or participation level was lower for relational leadership than for transitional and action functions, as was the density of face-to-face communication, likely due to distribution of the team designers.

Complexity measures provide an understanding of the network structure and its relationships. Complexity vectors were established for each network consisting of 29 different complexity measures addressing size, connectivity, clustering, and decomposition measures. The cosine distance measure was then used as an indication of similarity between all developed networks. Pairwise similarity comparisons indicated a high similarity between communication networks, and similarities between transitional and relational leadership functions with all modes of communications. Further, the action leadership functions exhibited higher cosine distance from communications network complexity vectors, which supports the observations of student teams using a leadership functions protocol [94]. The decomposition of the problem and a tendency to work individually or in organizational silos while performing analysis and technical functions supports this observation.

Future research is recommended to determine if these networks develop or change through the lifecycle of the project team and the role of project design team size on network characteristics. Additional similarity measures can also be applied for additional insights. Research is also recommended to determine if the degree (leadership) and frequency of influence involved in leadership are similar in the perceptions of student designers. The frequency of communications or leadership functions is also a probability of influence or information passed through these network relations [158].

5.4 Fall 2017 – Spring 2018: Aerospace Emergence Study

A third case was evaluated during the Fall 2017 and Spring 2018 semesters. This project was the same design problem and scenario as the aerospace project studied previously (5.3). The team composition and design characteristics were common with the first problem and are described in Table 5-7. Identical system boundaries were identified for the case study: only the internal members of the team were included. External members, such as the faculty and graduate advisor were not surveyed. The researcher served as a graduate student advisor for the team throughout the project.

5.4.1 Objectives

The objective of the 2017 – 2018 study was to understand the emergence of informal leadership structures over time. Faculty perceptions of emergence and structures were elucidated in the interview study as detailed in 4.3.4. However, the first case surveyed the participants at the conclusion of the two-semester long project. There were no intermediate survey points that could be used to evaluate emergent states of leadership and their development over time.

5.4.2 Surveys

The survey instrument, Table 5-6, employed in the spring 2017 study was used for this study. This ensured consistency with the previous studied and provided the information necessary to establish the informal leadership and communication structures. Survey dates were selected to allow sufficient time to elapse for discrete states and to avoid survey fatigue. Participants were required to complete additional surveys for the program sponsors throughout the course. The surveys also aligned with key progress points in the plan of actions and milestones.

The first survey was deployed during the conceptual design phase to establish an initial state. Participants were instructed to consider and assess a thirty-day period just prior to the survey date in October. The team had been working together for one month at this point in the project and had met for one in-person kick-off meeting. This kick-off meeting included a team building exercise and initial consideration of the problem statement and requirements development. The second survey was administered to cover a thirty-day period (November) just prior to the manufacturing design review—with the survey deployed right after this milestone brief. The period considered consisted of embodiment design. The final survey was administered in March just prior to the conclusion of the project. The thirty-day period considered for this survey consisted primarily of detail design, manufacturing and assembly.

5.4.3 Network Analysis

Leadership and communication networks were prepared using identical methods to the Spring 2017 case study (5.2). Each of the three survey points (October, December, and March) provided discrete sets of leadership and communication networks. These networks were then analyzed using the traditional social network metrics of density and degree centrality.

5.4.3.1 Density

Perceived leadership densities for the first survey point are provided as Figure 5-9. The vertical axis is the network density. Perceived leadership responses are indicated on the horizontal axis. The data value at a given perceived leadership threshold represents the density of the network for an adjacency matrix representing all relationships established at or below that level. Transition and action phase activities have nearly identical trends. The relational densities are lower at each threshold. This is consistent with observations in the protocol study to be discussed in 6.3.2.

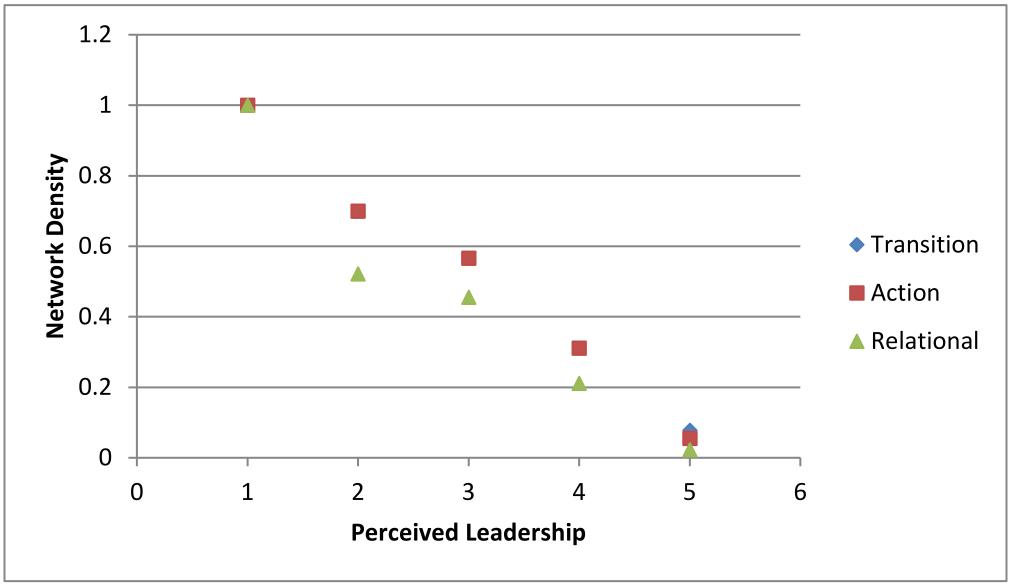

Figure 5-9. Leadership network densities: October

Communication network densities are included as Figure 5-10. Network densities are indicated on the vertical axis. The value indicates the density of a network of all relationships (edges) that are equal to or below the established threshold. The thresholds are indicated on the horizontal axis and correspond to the survey responses, with five representing frequently if not always. The individual series represent the separate modes of communication. Face to face is communication is generally limited by the number of individuals at the given location. Text and teleconference communications display similar linear trends. Face-to-face communication begins with a similar trend but appears to be limited to the relationships on sight, unless travel occurred during the period of interest.

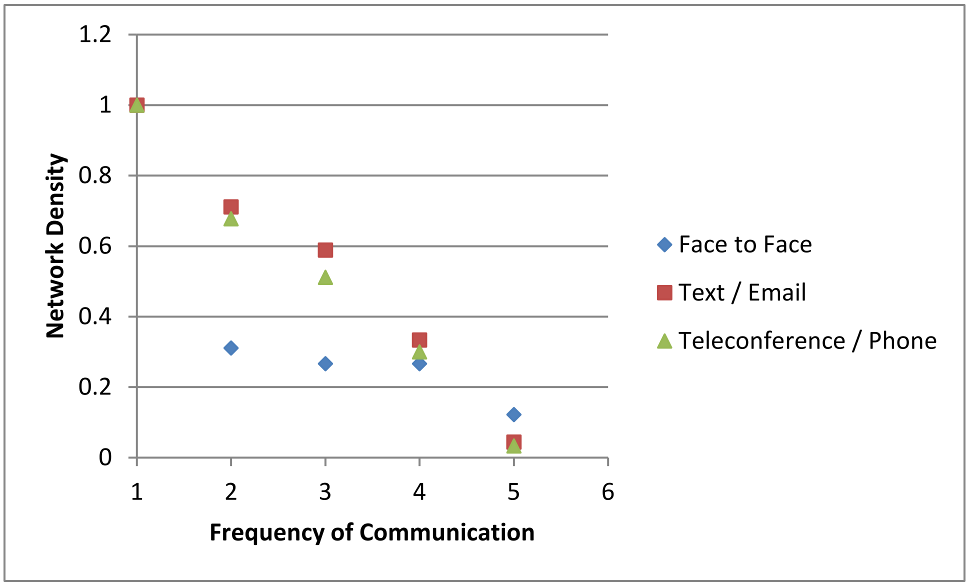

Figure 5-10. Communication network densities: survey point 1.

5.4.3.2 Temporal Network Development

The variation in network density is provided as an indication of the development of leader-follower relationships over the life of the project as Figure 5-11. Leadership network densities are arranged sequentially on the left of the figure. Communication network densities are arranged sequentially on the right. Densities are provided for each of the three leadership function types and the three modes of communication.

Leadership Density: October			
	TR	ACT	REL
5	0.078	0.056	0.022
4	0.311	0.311	0.211
3	0.567	0.567	0.456
2	0.7	0.7	0.522

Communication Density: October			
	F-F	Text	Telecon.
5	0.122	0.044	0.033
4	0.267	0.333	0.3
3	0.267	0.589	0.511
2	0.311	0.711	0.678

Leadership Density: December			
	TR	ACT	REL
5	0.144	0.167	0.122
4	0.433	0.433	0.344
3	0.667	0.667	0.489
2	0.800	0.800	0.567

Communication Density			
	F-F	Text	Telecon.
5	0.178	0.078	0.056
4	0.333	0.400	0.322
3	0.333	0.667	0.567
2	0.4	0.833	0.733

Leadership Density: March			
	TR	ACT	REL
5	0.211	0.2	0.111
4	0.489	0.489	0.344
3	0.622	0.622	0.556
2	0.678	0.678	0.578

Communication Density: March			
	F-F	Text	Telecon.
5	0.2	0.111	0.056
4	0.356	0.433	0.267
3	0.356	0.656	0.444
2	0.444	0.789	0.678

Figure 5-11. Leadership and communication densities at established thresholds.

The first series of surveys are provided at the top of the figure and establish a baseline for trends. Leadership densities increase in every function type and threshold between October and December. Similarly, communication densities are consistent or slightly elevated, at each threshold. This trend between the first and second surveys, or between conceptual design and embodiment, indicates some increase in the leadership and communication perceived by student participants. At the third survey point, the density of leader-follower relationships at the highest two thresholds increase; however, the overall density of these relationships at the lowest threshold (sometimes or greater) is slightly reduced. This perception change occurred during the manufacturing phase of the project, just prior to project completion and flight of the UAS.

5.5 Conclusions.

The preliminary case study served an exploratory function to establish objectives for future cases. It identified the complexity of two-semester teams functioning as multiteam systems and the importance of determining directional ties to understand leadership within these systems. These objectives were then pursued in Phase I and II studies. Phase II studies further explored the impact of size and organization on the emergence and distribution of leadership within the teams.

5.5.1 Distribution

Leadership structures and the distribution of leadership functions were examined across the three case studies. Student leaders were selected by their teams early in the project, consistent with the indications from faculty interviews (4.3.4). The final two case studies manifested the informal leadership structures within selected ten-person design teams. The densities of perceived leader-follower relationships at established thresholds were determined for each of the leadership function types in addition to communications densities. The densities of transition and action networks were similar, but, greater than relational network densities.

5.5.2 Emergence

Network densities indicate that leader-follower relationships increased in frequency and number between the first survey taken during conceptual design, and the second survey administered during embodiment design. The reason for this increase cannot be established, however, does merit future research. At the conclusion of the project during detail design and manufacturing, the number of frequently occurring leadership relationships strengthened while the overall network density decreased. While the reason is not established, this could result from the changing nature of design work during this late stage and corresponding changes in collaboration requirements. The same relationship was reflected in the communication networks.

5.5.3 Composition

The composition of teams was found to be a factor in the first case study. The larger, two-semester teams were composed of members from multiple, distributed institutions. This, in addition to their increased size, increased the complexity of their organization and leadership structures.

5.6 Summary

Chapter Five increased understanding of the emergence and distribution of leadership functions within novice design teams. These established student perceptions of leadership and communication structures and build on the understanding provided by faculty interview results. Chapter Six will focus on leadership behavior within the conceptual design activity of function modeling. This will be the subject of a protocol study of student design teams. Current progress in the dissertation and remaining topics are included as Figure 5-12.

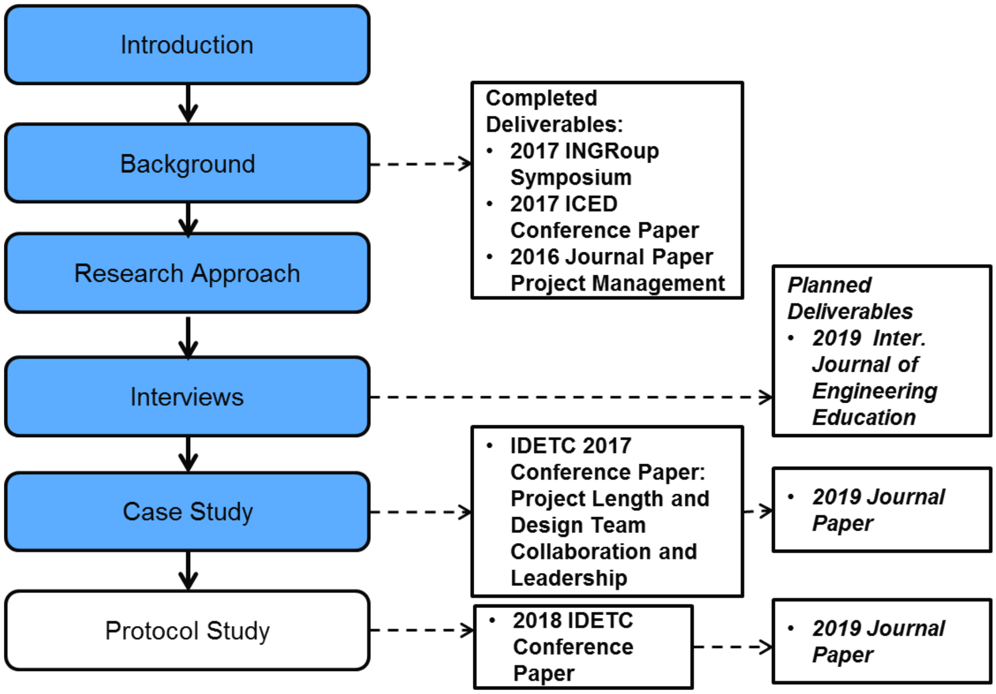

Figure 5-12. Dissertation Roadmap

CHAPTER SIX: PROTOCOL STUDY

A protocol study allows the observation of a designer(s) in a semi-controlled environment. This enables the researcher to answer research questions that require understanding how something is done, rather than just establishing the relationships between input and output variables. In other words, it determines what is happening inside the experimental "black box" instead of focusing on the inputs and outputs alone. Specific applications that drive the use of a protocol study include [164]:

- Understanding how designers think about an activity
- Establishing patterns that will allow the formulation of research questions for future research
- Testing hypotheses related to how designers complete an activity
- Determining designer methods for transition to novice designers.

The major advantages and disadvantages of protocol studies are summarized in Table 6-1. The protocol study was selected directly observe novice engineer design teams during conceptual design. This observation supplements the observations gained through the interviews and case studies in Chapter Five and Chapter Six. These studies also mitigate the disadvantages by providing natural observations and perceptions.

Table 6-1. Protocol study advantages and disadvantages.

Advantages	Disadvantages
• Understand how designer completes task • Provide insight into designer thought process	• Designers observed in laboratory rather than natural environment with potential to introduce bias • Significant investment of time to encode and analyze results

Protocol studies have been used in a variety of engineering design research contexts. They have been used to map and understand the overall design process and develop descriptive and prescriptive models [165,166]. They have also been used to explore specific phases of the design process or specific activities such as sketching [167,168]. Figure 6-1 depicts the protocol study within the research approach. The protocol study addresses research questions one and two.

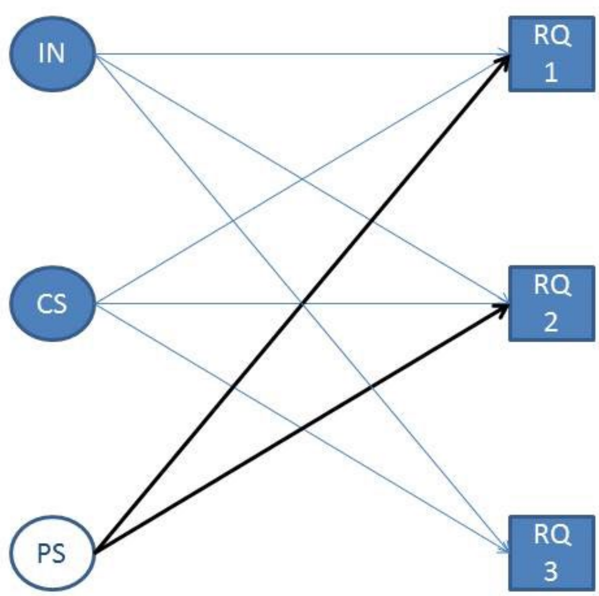

Figure 6-1. Protocol study within the overall research approach

6.1 Purpose

The purpose of this protocol study is to explore the emergence of leadership and the distribution of informal leadership within student design teams during the concept generation activity of function modeling. Protocol studies have been used to establish the function model chaining preferences of individual student designers [169,170]. This corresponds to research questions one and two stated in Table 6-2 while the interview studied faculty perceptions on these research questions. The protocol study will examine the same questions in a more controlled context, where the design problem and team composition can be more closely controlled, and the behaviors more closely observed. It also allows a focus on a specific design activity. In this way, the behaviors will be triangulated within similar although not identical contexts with distinct research methods.

Table 6-2. Research questions explored through protocol study.

RQ 1: How does leadership emerge in engineering design team and how are leadership functions distributed within the design team?
RQ 2: How does composition (size, organization) impact leadership structure (position and functional distribution) in engineering design teams?

6.2 Protocol Study Development

There are several established methods available for use in a protocol study. Two fundamental decisions must be made: will observation be direct or indirect, and how will the activities be recorded. Traditional direct observation techniques include the think-aloud method. This method requires that the designer verbalize his thought processes while performing design activities. Researchers can understand the participants thought processes in real time and record these observations with a clear correlation to time of occurrence. Unfortunately, this also results in an unnatural environment for the designer.

This effect can be mitigated by training the participants and increasing their comfort level through practice and familiarity.

Retrospective methods involve recording the designer in a more natural environment. There is always some artificiality in a laboratory environment—it is only reduced. The designer completes the activity as he desires while the results are recorded, and the researcher extracts the thought processes, as required, after the observation is complete. This can be done by allowing the participant to narrate his own recording, or by actively interviewing the participant to extract his thoughts at that specific time. While this approach is more natural for the designer, it can introduce an alternative bias. The designer may have difficulty accurately recalling his thoughts and may even modify them after the fact based on what he thinks is a preferred response. The researcher should consider the advantages and limitation of each approach when deciding to select a real-time or retroactive approach. The study designer will have to decide what is more important to his study [165].

Table 6-3. Common protocol study methods.

Protocol Study Methods
• Video recorded • Other capture systems • Documents (collected) • Think-aloud • Retrospective

This protocol study was retrospective and used video recording to capture the design team's activities. Video recording allows analysts to observe the behavior at their own speed and with a clear correlation to the time sequencing of events. Screen or board "capture" technologies were used to observe the development of design artifacts without having to mentally declutter the picture to remove the designer from the field of view. This approach minimized the intrusiveness that is characteristic of methods such as the think-aloud technique. The think-aloud technique was also impractical in this group setting. The combination of group communication and verbalized thought would be difficult and disorienting for participants and analysts in this setting.

6.2.1 Protocol Development [66]

A protocol was established to enable the identification of leadership behaviors during the study [94]. The functional leadership behaviors are those identified in section 2.5.2. They are also consistent with the functions employed in the interview analysis and the case study. The functions are categorized by their temporal framework as transition, action, or relational/interpersonal. The protocol coding guide developed in [94] is provided as Appendix B and includes instructions on the meaning of each function, some sample behaviors, and how to properly use the coding spreadsheet. The study objectives also require that the time of each observation is recorded in addition to identifying the leadership functions, leaders, and followers.

The protocol was evaluated using a design team from the study population. Video from one team was coded and analyzed in four, ten-minute segments. Each segment was coded by at least two and up to four designers to establish reliability. Figure 6-2 is a sample of the observation data sheet developed for the protocol study [66].

	Time Recording			Leadership	Design Activity Coding		Individual Behavior Coding					
Number	Start Time	End Time	Duration	Leadership Function	Design Space	Design Activity	Per. A	Per. B	Per. C	Per. D	Per. E	Per. F
1	0:01:17	0:02:15	0:00:58	SM			L	F	F			
2	0:02:25	0:02:40	0:00:15	SM			F		F	L		
3	0:03:45	0:04:00	0:00:15	SM			F			L		

Figure 6-2. Sample observation data sheet.

6.2.2 Participants

Each team consisted of four engineering design students. The members were selected from two graduate student populations. The first population was a National Science Foundation funded summer course hosted at Clemson University. The course provided instruction on collaborative design research methods to graduate students from a variety of domestic and international universities. The graduate students have a similar level of experience and educational background as novice engineers in industry, however, their undergraduate backgrounds and instruction on design methods are not homogenous. This population will be labeled as population A in all further results and discussion. Six teams of either three or four members were formed from the course. Video results from one team were excluded since it was not possible to identify all the designers' leadership activities due to their locations with respect to the camera's field of vision. Teams will further be designated as A.1 through A.5, with the letter designating the population and the number representing the specific team [66].

The second population included students from ME 8700 at Clemson University. This course includes instruction on advanced design methodologies. However, the designers are all students from Clemson University. Their backgrounds on design methods such as function models are also much more uniform. Four teams consisting of three or four members were formed from this group and are designated as B.1, B.2, B.3, and B.4.

The students had been in the course for approximately one month at the time of the study sessions.

The teams were not pre-formed and did not have pre-established leadership structures. This team size is consistent with many Capstone design teams at Clemson University and is designed to allow each student to remain engaged in the process and to interact as active team members. Nine teams consisted of 35 total participants in coded sessions.

6.2.3 Design Problem:

The design problem must effectively prompt the desired activity: it must provide suitable context for the construction of a function model that can be completed in the targeted time frame. The design problem selected has been previously established as appropriate for studies of function modeling by individual designers [169]. It has also been used in a pilot study with a group of four designers to ensure its appropriateness and effectiveness as a prompt.

The design problem was stated as:

Design an automatic recycling machine for household use. The device should sort plastic bottles, glass containers, aluminum cans, and tin cans. The sorted materials should be compressed and stored in separate containers. The amount of resources consumed by the device and the amount of space occupied are not limited. However, an estimated 15 seconds of recycling time per item is desirable. [171]

6.2.4 Function Models

Conceptual design is the stage during the systematic design process that develops concepts from a set of design specifications [8]. A concept is an abstraction of a future product that will be further refined, embodied, and detailed, in the remainder of the design process [5]. The stage begins with a requirements, or specifications, list that has been established during the planning and task clarification stage [5,8]. An early step in this process is the determination of the overall function of the product. The function is the definition of the inputs and outputs of a system [8]. The function is then decomposed into subordinate functions referred to as sub-functions. These sub-functions are connected with flows of material, energy, and information. This arrangement comprises a model known as a function structure that can be used as an input to the generation of unique concepts for further evaluation and selection of primary concepts to be developed. Each participant has had an introduction to function structures in their design course prior to this activity. Students are provided a survey to establish their expose to function modeling.

6.2.5 Facility set-up and Data Recording

The engineering design teams were required to construct a function structure given the design problem provided above in 6.2.3. Each team was provided with the same facility and equipment set-up. The facility was a room used for design reviews and other design activities within the mechanical engineering department. There was a table in the center of the room, sufficiently large to hold a white board that will be used to construct the function model. The board is pictured in Figure 6-3. The function model on the board is the product of a team generated function structure that was recorded for later analysis as part of this protocol study.

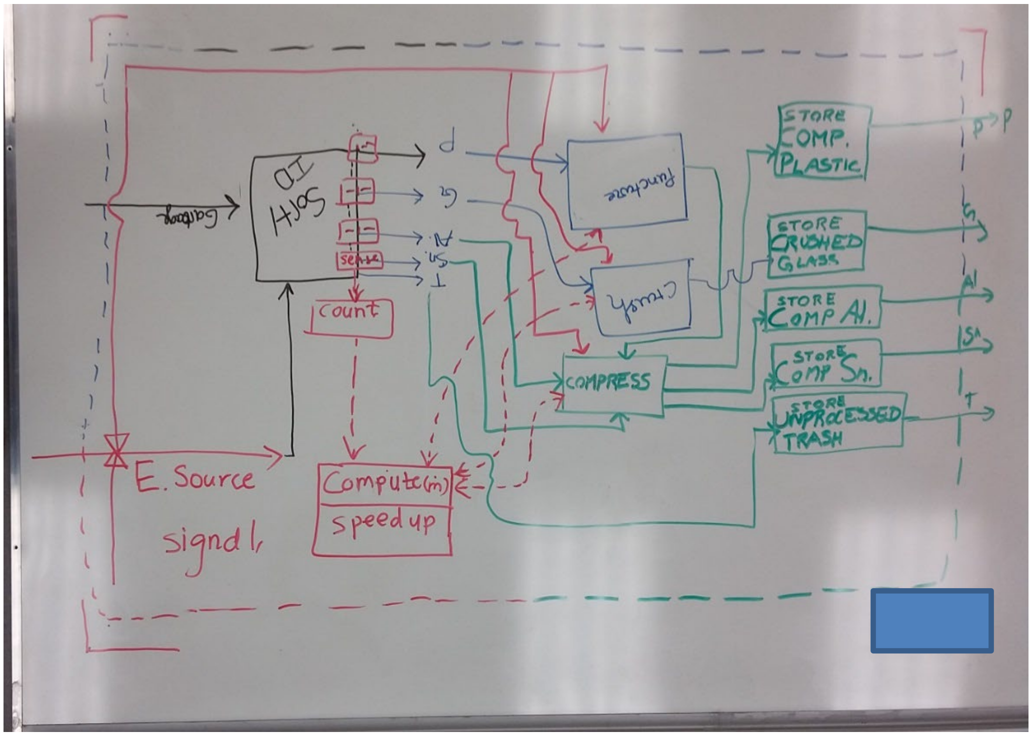

Figure 6-3. White board for function modeling and data recording with sample team product

A capture device was connected to the edge of the white board that will capture each marking on the board. In Figure 6-3, the participants had markers that were red, black, green, or blue. The different colors enabled correlation of markings to specific members of the team. An eraser was also provided for the team to edit their function structures.

Two video cameras were also placed in the room to record the function structure, and the team's actions and interactions. The video recordings can be correlated to the white board capture system recordings by time. The video recordings were needed to enable observation and analysis of team leadership and follower behaviors and communication.

The white board and table were large enough that the team members can stand around the board to discuss and construct the model. Each member had access to the table. There was sufficient room to move around the board if needed. The model provided in the figure provides some insight into a normal orientation of the members to the board and the model. The members possessing red and green markers are clearly on one side of the board, while the other two members are on the other side of the board as indicated by the inverted writing with respect to the page. The students' positioning around the board was not constrained by instructions to the participants. Participants selected their positioning around the board and were also allowed to re-position freely.

6.2.6 Function Model Coding

The recorded sessions were coded for leadership behaviors and function model development. The leadership and member behaviors correspond to the functions listed previously in Table 2-3. Function structures were coded for the construction of the model itself. Each object that was drawn or written was recorded and time stamped by the evaluator. Each object was further coded for its topology. The topology is defined as the identification of the flow of the object, or which object it is connected to and the direction of the flow [169]. This coding format has been established in previous studies intended to describe and understand how designers build function models. Figure 6-4 is an activity graph depicting the addition of objects to, or subtraction of objects from the model with respect to time in the design episode. Successfully coded leadership behaviors may be superimposed over the activity graph of the model to seek insights on the influence of leadership on the construction of the model.

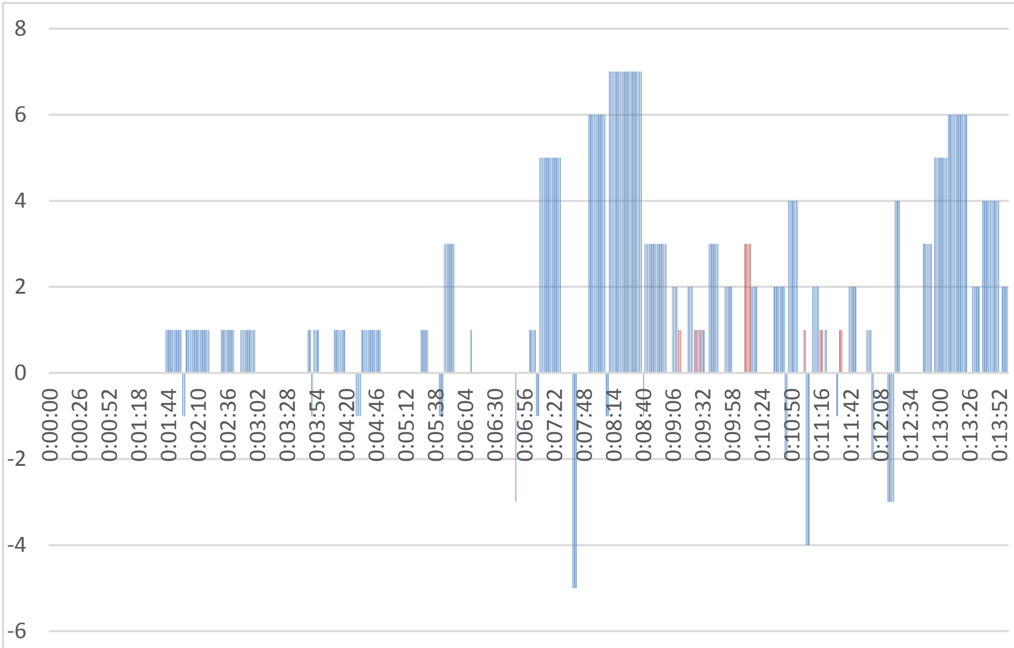

Figure 6-4. Representative activity graph of function model build from data in individual designer protocol study [169]

6.3 Protocol Study Results

Table 6-4 provides a summary of the overall duration of the function modeling sessions for both study populations. The total observation time for each population was approximately equivalent, with a difference of less than 15 minutes. Population A, NSF, sessions were on average 6 minutes and 16 seconds shorter than population B. This may be related to the fact that Population B, ME 8700, typically performed the experiment during a normal class time. While their activity was not tied to the length of the class, the comments of individuals near the end of sessions indicated a cognizance of the normally scheduled end of class. Population A sessions were during the summer and were not tied to a normal classroom routine. This may account for the slightly longer sessions for Population B as they considered the normal 50-minute class session length.

Table 6-4. Total duration of recorded function modeling sessions by team.

	Team	Session Length	Group Totals
NSF	A 1	0:51:05	Population A Total observation time: 3:18:07 Average Session Length: 0:39:37
	A 2	0:40:20	
	A 3	0:38:02	
	A 4	0:38:02	
	A 5	0:30:38	
8700	B 1	0:45:42	Population B: Total observation time: 3:03:30 Average Session Length: 0:45:53
	B 2	0:53:28	
	B 3	0:46:25	
	B 4	0:37:55	

Despite this small difference, the session lengths between both populations are comparable with a total range of 22 minutes and 50 seconds between the shortest and longest sessions and a standard deviation of 7 minutes and 18 seconds. The similarities in average length suggest that the results may reasonably be compared within the context of normalized lengths. Each function modeling session has been subdivided into quintiles to allow comparison of results between teams.

6.3.1 Leadership Function Occurrences

One indication of the leadership exhibited is the number of occurrences of each leadership function during the function modeling session. The occurrences from each of the nine sessions are summed by individual function and summarized in Figure 6-5. Only nine of seventeen leadership behaviors were observed during the study's recorded sessions. This is not surprising based on the focus on one specific design activity during the conceptual design phase. For example, managing boundaries would not be frequently anticipated based on the small team size and the absence of external customers or designers to interact with. This function would be reasonably more frequent in a less controlled scenario as might be explored in a case study of an industry team or student team.

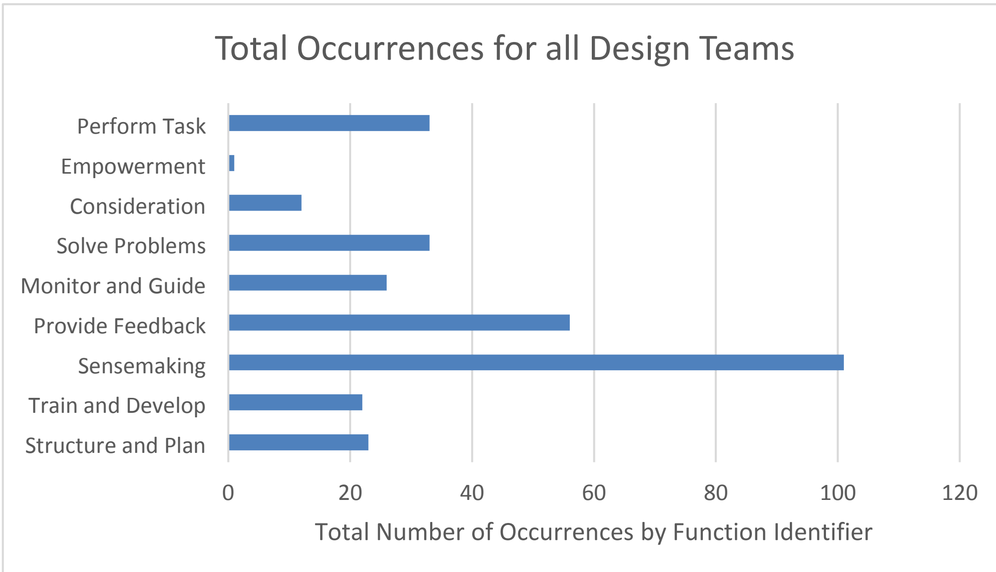

Figure 6-5. Total leadership behaviors observed by function

Sensemaking and providing feedback were the most frequently observed behavior in the recorded sessions with 101 and 56 occurrences respectively. Empowerment and consideration are the least frequently observed of the behaviors observed with twelve and one observations respectively. These observations are consistent with results from an initial case study conducted using the same protocol [94]. They also suggest that functions should be considered by temporal characterization (transition, action, relational). The most common two functions are transition activities. The least common two functions observed are relational activities. The most common are transition functions and the least common observations are relational (keeping in mind that several behaviors were not observed at all). Observations aggregated by type are addressed in 6.3.2.

A side by side comparison of the total occurrences by population does suggest that while the results are comparable, there are distinctions. Total occurrences by population are provided in Figure 6-6. Sensemaking and provide feedback are the most frequently occurring functions in both groups just as they are for the overall study. Sensemaking is far more frequent in the ME 8700 population. The results are comparable with 151 total observations for the NSF population and 156 total observations across the ME 8700 population.

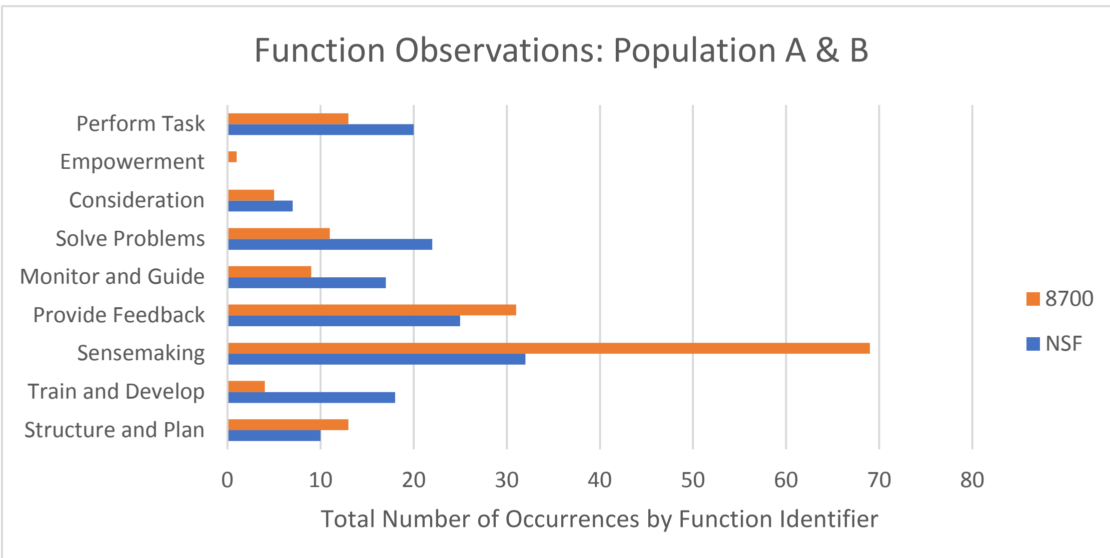

Figure 6-6. Leadership function observations by population

Figure 6-6 also indicates that training and developing was observed more frequently in the population A design teams. This may reflect differences in the populations and their backgrounds. As discussed in 6.2.2, the participants in population A were from a range of domestic and international universities. Differences in their understanding of and approach to function modeling were apparent. Many participants approached function modeling as black box diagrams of functions as described in [5,8]. At least one designer mentioned the interaction between the user and the object or function, suggesting an alternative approach. The teams in this group devoted more time to establishing a common understanding of the purpose and procedure for function modeling: this is reflected in the frequency of training and development behaviors. It is also possible that the time devoted to this training and development function affected the frequency of sensemaking and other functions.

6.3.2 Frequency of Type Occurrence

Initial efforts to apply the leadership behaviors protocol to a case study of capstone design teams suggested that behaviors should be grouped to simplify coding and increase reliability between coders [94]. This study performed base coding using the full list of functions to maintain the granularity of specific functions during the exploration of function modeling as a unique design method. Occurrences were then aggregated into their appropriate temporal categories (transition, action, relational). This approach allowed the analysis to be related to the phase level analysis conducted in the case study network analysis, without sacrificing the identification of individual functions possible through retroactively coding video sessions. If multiple coders are required, it may be desirable to code initially by larger categories that correspond to the temporal phases.

The occurrences aggregated by function type are included as Figure 6-7. Transition functions occurred more than twice as frequently as action functions. Relational functions occurred at a much lower frequency than either of the previous two categories. This may be related to the conceptual nature of function modeling. Interpreting, communicating and representing information to the team would be expected to be a significant portion of conceptual activities. A similar trend is noted in the case study previously analyzed via this protocol although the observations in that case study spanned a greater portion of the design process [94].

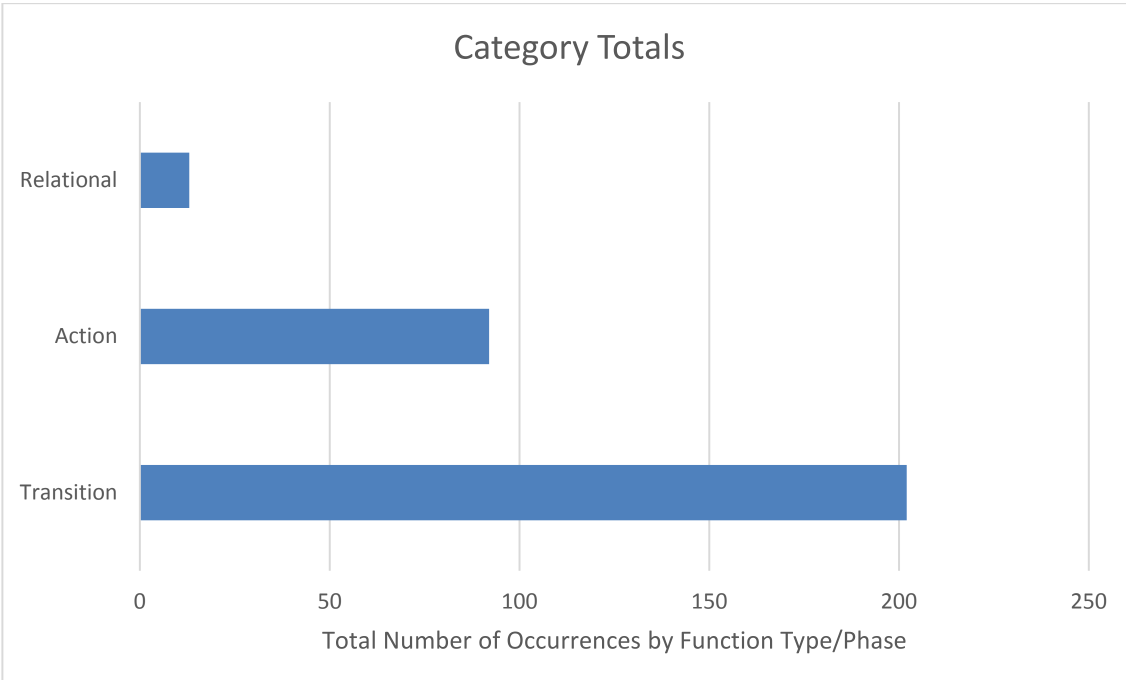

Figure 6-7. Total observations categorized by function type.

Leadership behaviors by grouping are indicated in Figure 6-8. Notably, both populations have nearly identical occurrences of relational activities. While the ratios of transition to action phases are not identical, the ordering is the same. In all populations, transition activities were predominant and action phase was the second most frequently observed. Relational activities were infrequently observed during these short sessions in both populations. This may be related to the short duration of the sessions and to the conceptual nature of the work.

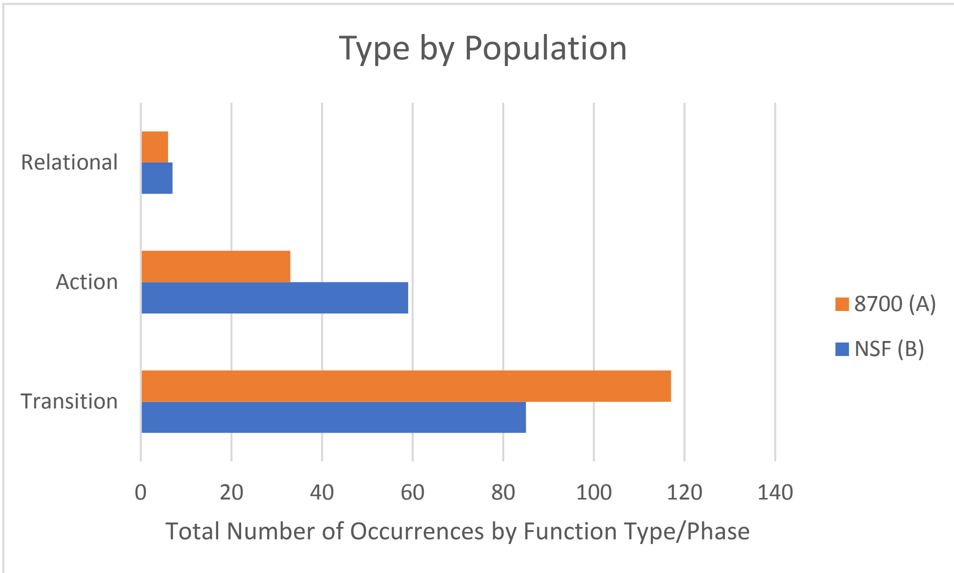

Figure 6-8. Functional leadership behavior occurrences by function type for each population (A and B).

6.3.3 Temporal Distribution

The distribution of the leadership occurrences by quintile for population A are included as Figure 6-9. The elapsed time was divided into periods to assess occurrences temporally within each interview. Initially five and ten-minute periods were used, however, quintiles were used to normalize results and allow comparison of individual teams. Quintiles were sufficiently large to understand and visualize trends within the recorded periods while avoiding excess sensitivity. Occurrences were assessed to the quintile they began in since some occurrences overlap the boundaries of the period.

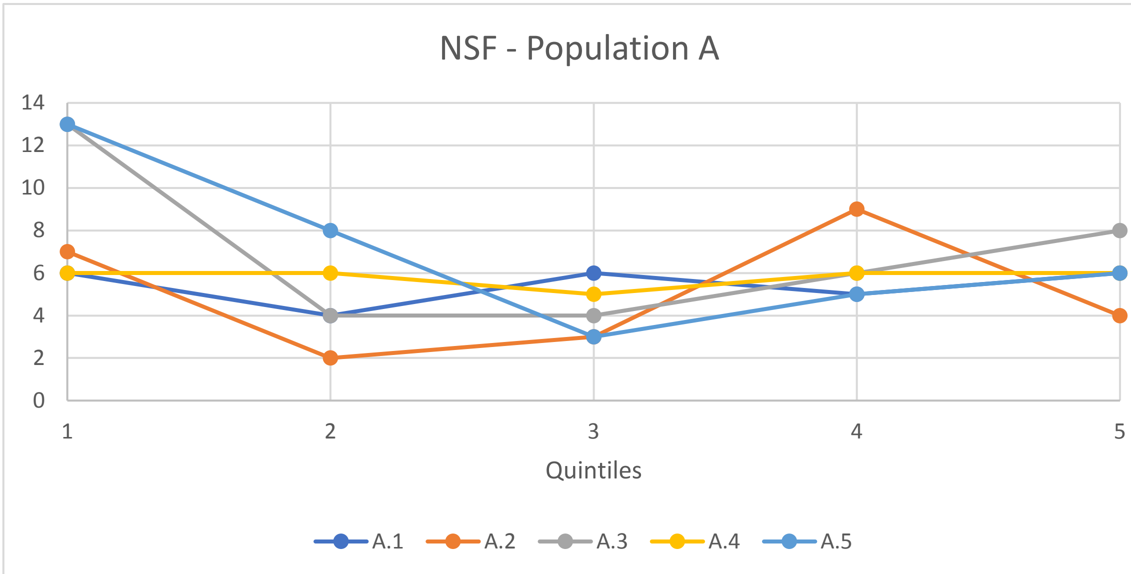

Figure 6-9. Temporal distribution of leadership occurrences for the NSF Population (teams A.1 through A.5).

While there is variability in the results of the teams, the function modeling sessions tend to begin with an elevated observation of leadership behaviors, followed by a reduction in the second quintile. In the final quintile, the behaviors increase slightly. This trend remains when aggregating the results of teams into population and total results. These aggregated results are depicted in Figure 6-10**.** The solid lines in the figure are the aggregated results for all the teams in one population. The average results of both populations are then plotted along with a trend line.

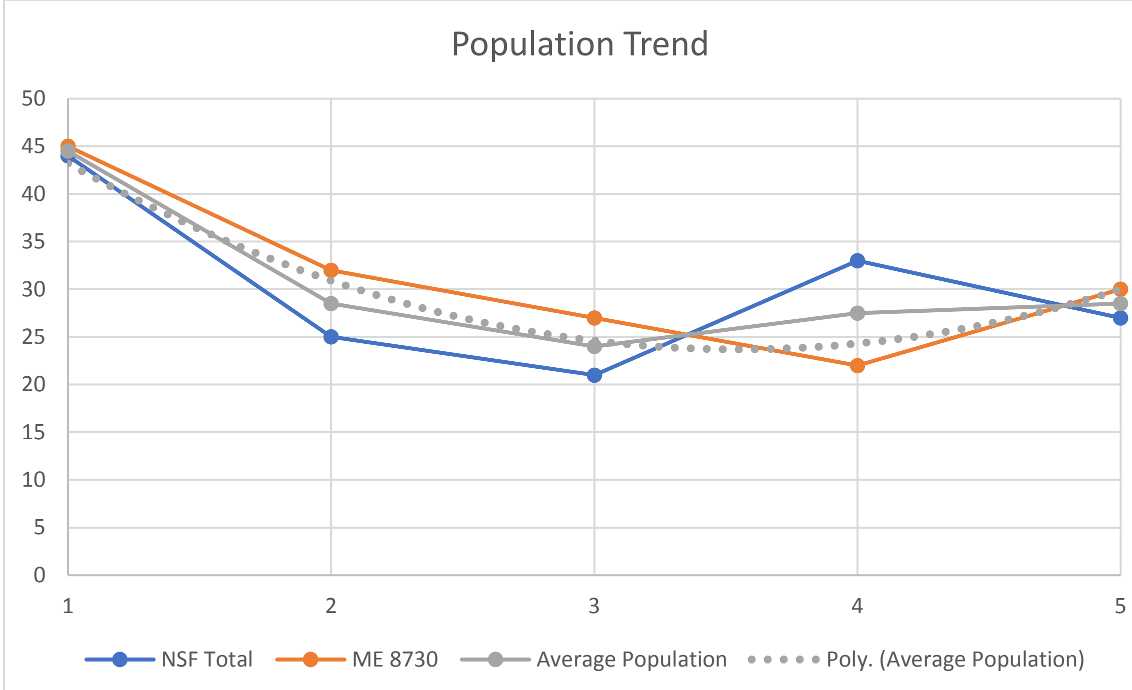

Figure 6-10. Population trends for leadership occurrences by quintile.

These results indicate an increased activity while informal leadership structures are emerging during these limited duration activities. A relatively consistent rate persists for the remainder of the activity. The final activities to complete the function modeling result in a slight elevation in influence activities.

The results are refined by considering the occurrences by leadership function type. The results by function type are provided for two teams, A.2 and B.2 in Figure 6-11 and Figure 6-12. In each case, transition activities are dominant in the first quintile. The frequency of action activities appears to remain consistent throughout the function modeling activity. In A.2, it appears that there are no observed action activities until the third quintile. B.2 maintains a stable level of action behaviors, although none are observed in the third quintile. Relational activities occur infrequently and there is no discernible trend for their occurrence in this protocol study.

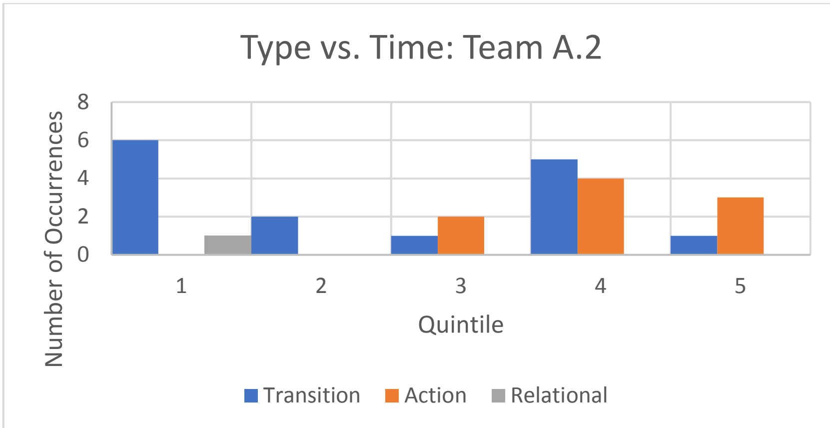

Figure 6-11. Type of leadership activity by quintile for team A2.

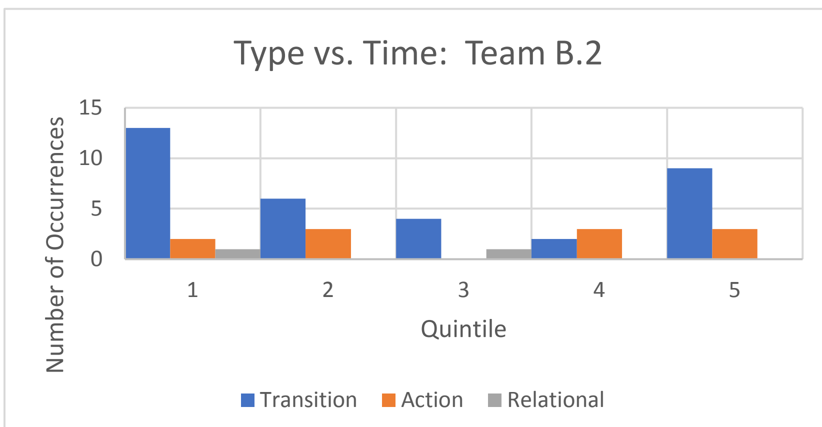

Figure 6-12. Leadership Occurrences by Type for Team B2.

6.3.4 Distribution of Leadership Functions

The distribution of leadership behaviors among the design team members are an indication of leadership structures within the team. Since the design teams in the study do not have formal structures, they are indicative of informal structures. Leadership behavior occurrences are summed for each team by designer. The designers are numbered from one to four in each team. Team A.3 has three members and designers from one to three. The numbers were assigned at the time of coding in order to preserve the anonymity of participants. No systematic method was applied to number the designers. In most cases the designers were numbered in a clockwise fashion to facilitate efficient coding. However, the first designer numbered is random. Designers could move around the table naturally without restriction, so identifying characteristics were noted at the beginning of each coding session, such as the color or pattern of the individual's shirt. The results for session A.2 are included as Figure 6-13.

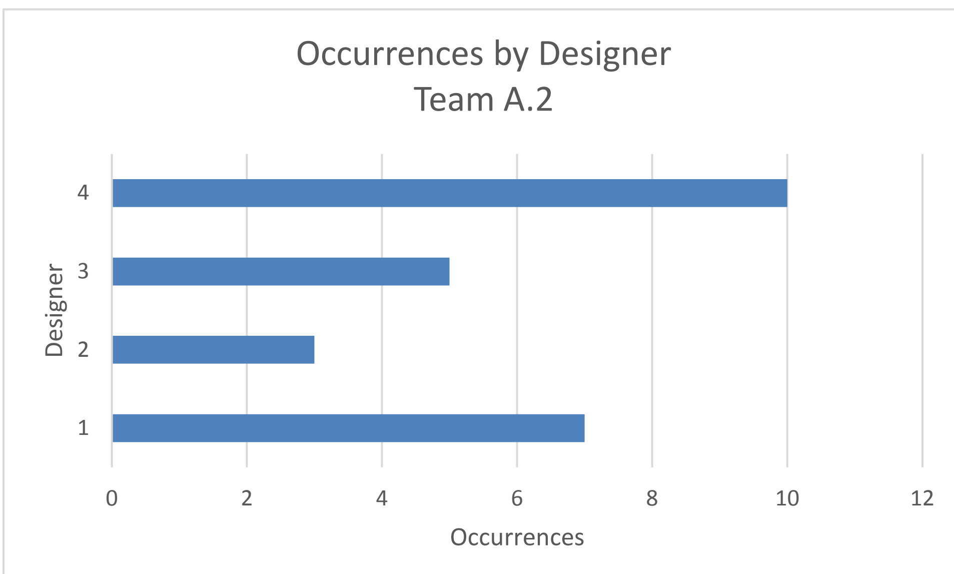

Figure 6-13. Leadership occurrences by designer for Team A.2.

The designers assigned number is included on the vertical axis, while the horizontal axis indicates the number of observed and coded behaviors. There is variability in the number of occurrences per leader: there is a distribution in the fulfillment of leadership functions by the members of the team. Each team has its own informal structure that developed during the session. The emergence of these structures by quintile of time will be discussed in 6.3.6.

6.3.5 Follower Relationships

Each observed leadership behavior has a corresponding follower relationship. The number of occurrences per designer and corresponding percentage of the team total are included in Table 6-5 for Team A.2. The number of followers and the average number of followers per occurrence are also included. This information provides an indication of the centrality and span of influence for each leader.

Table 6-5. Leader - follower summary for Team A.2.

Designer	Occurrences	% Total	Followers	Followers per Behavior
1	7	28	15	2.14
2	3	12	4	1.33
3	5	20	8	1.60
4	10	40	19	1.90
Total	25	100	46	1.84

Figure 6-14 is a visualization of each designer's total count of observed behaviors verses the average number of followers. Designers with a high frequency and a high number of followers could be considered to have the highest influence in the team. However, designers may also a low number of leader behaviors and a high number of followers, implying that they may still be highly influential when they choose to lead. There is no discernible relationship between the number of followers and the frequency of leader behavior. It does, however, provide an indicator of their role in the informal leadership structure of the team and their degree of influence during the activity.

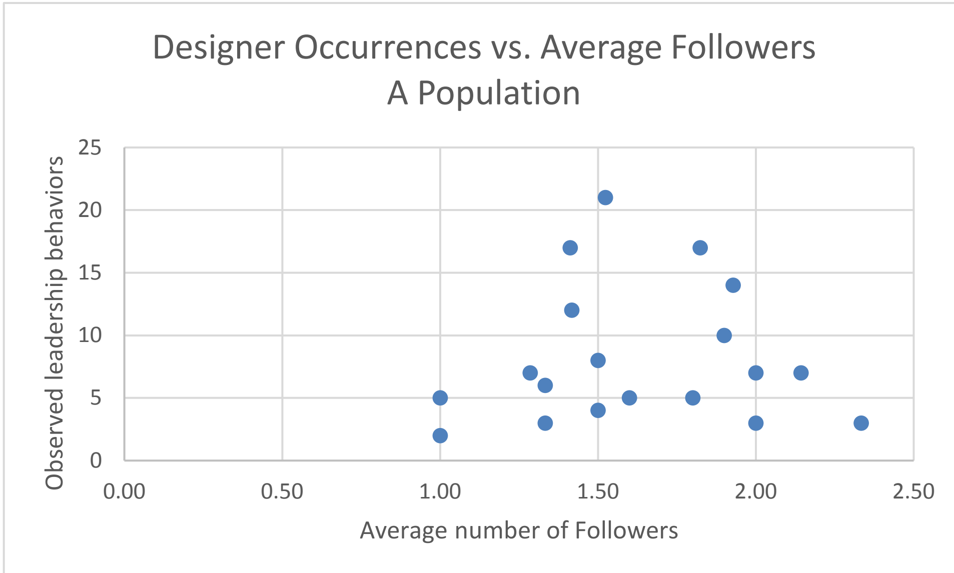

Figure 6-14. Individual designer's plot vs. the average number of followers for population A (NSF).

6.3.6 Emergence of Leaders

Leadership structures may be represented as a directed graph or network [64]. The leadership interactions between novice engineers during the design session are used to identify these informal structures. The designers are the nodes of the graph and the leadership interactions are the edges. This is consistent with the format used in the case study (5.4). The edges are weighted with the number of interactions between team members. Figure 6-15 is the matrix representation of the leadership interactions for Team A.1. The edges are directional resulting in a matrix that is not symmetric.

A1

Q1

0	1	2	3	4
1	0	1	1	0
2	1	0	0	0
3	0	0	0	0
4	4	0	2	0

Q2

0	1	2	3	4
1	0	0	0	0
2	0	0	0	0
3	1	0	0	1
4	4	2	3	0

Q3

0	1	2	3	4
1	0	0	1	2
2	0	0	0	1
3	0	0	0	0
4	1	3	1	0

Q4

0	1	2	3	4
1	0	0	0	1
2	0	0	0	1
3	0	1	0	1
4	1	1	1	0

Q5

0	1	2	3	4
1	0	1	1	1
2	2	0	0	2
3	0	0	0	0
4	2	2	0	0

Figure 6-15. Matrix representation of informal leadership interactions by quintile, Team A.1.

The networks are then graphically represented as in Figure 6-16. The nodes, designers, are represented as circles. The edges, interactions, are represented by the areas indicating the direction of influence. The source of the arrow is the leader and the sink the follower in a given interaction. The thickness of the arrow is a function of the number of interactions occurring between two designers, in the direction indicated, in a given quintile of time. In the first quintile, there are five relationships (edges) established. Designer four, far left, influenced designer one, top, four times. The arrow is weighted to indicate this as four occurrences. The arrow from designer one, to designer three, bottom, indicates one occurrence. There were occurrences in both directions in the first quintile between designer one, top, and designer two, right. In the second quintile, dashed arrows depict relationships that have been established through observed leadership behaviors but were not active during this quintile [172]. The network graph in the fifth quintile depicts all leader-follower relationships that were established by observed behaviors during the session.

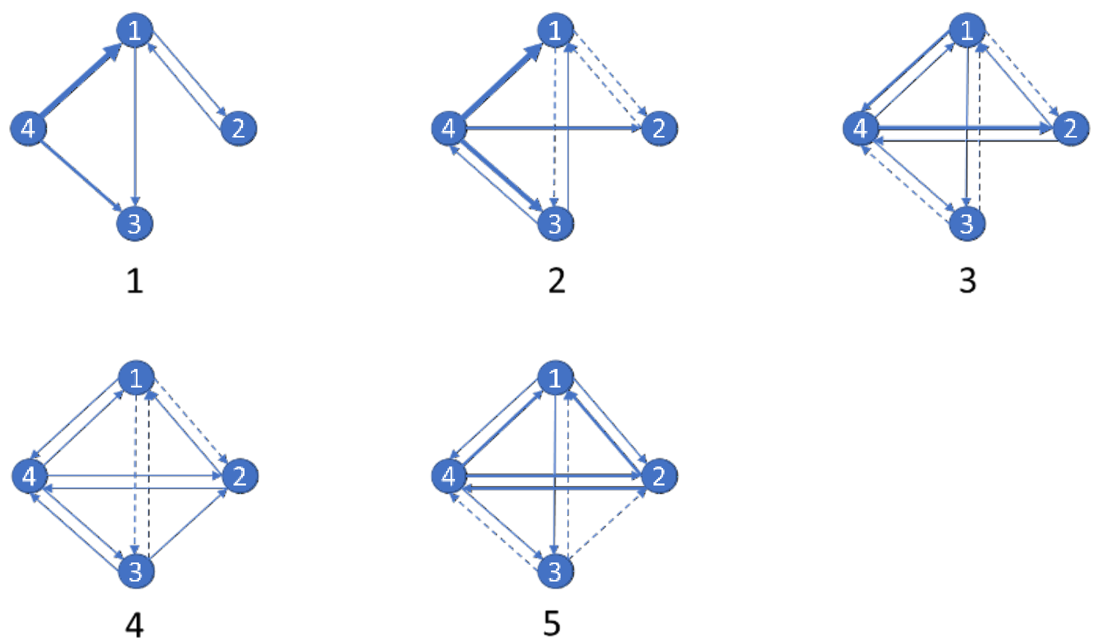

Figure 6-16. Time dependence of leadership (influence) network of team A.1 by quintiles.

Degree centrality provides a measure of the leader's position within the leadership network [148]. Degree centrality in the protocol study networks is calculated in two cases and provided in Figure 6-17. In the first case, each relationship is weighted by the number of interactions between leader and follower. This "weighted" centrality indicates the total number of leadership behaviors originating with each designer in the specified quintile.

The designer's identifier is included on the vertical axis of the matrix, and the quintile is indicated by the roman numeral on the horizontal axis. Out degree centrality is next provided unweighted: the degree measures the number of leader-follower relationships originating with the designer. This out degree centrality is a measure of the number of leader-follower relationships (edges) with that designer as the source. The number of occurrences is not considered, as long as there is one occurrence.

Weighted Out Degree Centrality

	I	II	III	IV	V
1	2	0	3	1	3
2	1	0	1	1	4
3	0	2	0	2	0
4	6	9	5	3	4

Out Degree Centrality

	I	II	III	IV	V
1	2	0	2	1	3
2	1	0	1	1	2
3	0	2	0	2	0
4	2	3	3	3	2

Rank Weighted (Out)

Des	Q1	Q2	Q3	Q4	Q5
1	2	3	2	3	3
2	3	3	3	3	1
3	4	2	4	2	4
4	1	1	1	1	1

Rank Unweighted (out)

Des	Q1	Q2	Q3	Q4	Q5
1	1	3	2	3	1
2	3	3	3	3	2
3	4	2	4	2	4
4	1	1	1	1	2

Weighted In Degree Centrality

	I	II	III	IV	V
1	5	5	1	1	4
2	1	2	3	2	3
3	3	3	2	1	1
4	0	1	3	3	3

In degree Centrality

	I	II	III	IV	V
1	2	2	1	1	2
2	1	1	1	2	2
3	2	1	2	1	1
4	0	1	2	3	2

Rank Weighted in

Des	Q1	Q2	Q3	Q4	Q5
1	1	1	4	3	1
2	3	3	1	2	2
3	2	2	3	3	4
4	4	4	1	1	2

Rank Unweighted in

Des	Q1	Q2	Q3	Q4	Q5
1	1	1	3	3	1
2	3	2	3	2	1
3	1	2	1	3	4
4	4	2	1	1	1

Figure 6-17. Weighted centrality (occurrences), unweighted centrality, and centrality ordering of protocol study leadership networks.

The designers then receive a rank for each centrality measure during that quintile. In the first quintile (I) for this team, designer one (1) had the most observed behaviors so she is ranked as one for that quintile. Designer three had the second most observed behaviors. Designers one and three each had the same number of designer follower relationships during this period and received a rank of one. In this team, three of the four designers received a ranking of one during at least one period in both centrality measures.

Designer one received three first rankings in both centrality measures. In the weighted case, designer four was next highest with two. However, both designers one and four had the same number of first unweighted ranks.

Table 6-7 provides the number of instances that each designer held the highest out-degree centrality. The maximum number of top rankings for one designer on each team is in bold font. This number indicates how many quintiles the designer was the most active or central contributor of observed leader behaviors for the respective measures of occurrences and unweighted centrality.

	A1	A2	A3	A4	A5	B1	B2	B3	B4
1	0	2	2	**4**	**4**	**3**	**3**	2	**5**
2	1	1	1	0	0	1	0	0	0
3	0	1	2	0	0	1	**3**	**4**	0
4	**5**	**3**		1	1	0	1	2	0

Team Maximum 1st Rankings: Average= 3.7, Median=3, Mode=3, Standard Deviation=1

Table 6-6. Number of occurrences first (1) rankings for each designer.

Out Degree Centrality

	A1	A2	A3	A4	A5	B1	B2	B3	B4
1	2	**3**	**4**	**4**	**3**	2	2	**2**	**4**
2	0	1	2	0	0	**3**	2	0	0
3	0	1	3	0	2	2	**3**	**2**	1
4	**4**	**3**		2	1	1	2	1	0

Team Maximum 1st Rankings: Average=3.25, Median=3, Mode=3, Standard Deviation=0.7

Table 6-7. Number of out-degree centrality (unweighted) first (1) rankings for each designer throughout the design activity.

The tables demonstrate that the most active designer for a team was the same in three out of five quintiles (median and mode). In five out of the nine teams, the most active designer for a team was the same for at least four quintiles. Similar trends manifest in out-degree centrality with the most central leader remaining the same in three of five quintiles (median and mode). In four of nine teams, the most central leader (unweighted) was the same during four quintiles.

6.4 Protocol Study Conclusions

The protocol study examined leadership behaviors in team function modeling sessions. This focused analysis to a more refined scope than the case studies and interviews and capitalized on the strengths of protocol analysis. The studies objectives addressed each on research questions two and three: emergence and distribution. Some insights into team composition, RQ3, were also achieved.

6.4.1 RQ 1: Emergence

Teams entered the function modeling sessions without formal leadership structures. The teams tended to begin with their highest levels of observed leadership behaviors in the first period of the session. These activities included transition activities such as sensemaking while the informal leaders influenced the teams by interpreting the design problem and requirements and communicating their ideas to the team. Once established, the designers with the most observable leadership behaviors continued, in most cases, to perform leadership functions throughout the session. While relative quantities of leadership behaviors do adjust between the designers on a team, the most central and active leaders were consistent in the majority of periods (quintiles).

6.4.2 Distribution

The network densities apparent in the leadership networks depicted in Figure 6-16 and Appendix B demonstrate the distribution of leadership functions during the activity. Leadership activities are not performed by a single team member; but are performed across the team at varying frequencies and activity levels. There is also a variation in the average number of observable followers for each leader's behaviors. The fifth quintile network graph provides a visual representation of all of the leader-follower relationships observed during the function modeling session.

6.4.3 Composition

Leadership networks across the three-man team were flat and dense (Appendix BProtocol Study Adjacency Matrices and Networks). The small size of the team appears to facilitate this result, although not generalizable due to only having one observation. This may encourage higher participation in conceptual design by limiting the group size, however, it could potentially limit opportunities for leadership experience in undergraduate teams.

6.5 Dissertation Roadmap

The research approach and methods have been detailed in the preceding sections. Chapters four through six have detailed each of the proposed research methods. Chapter Seven will present remaining work and the estimated labor requirements for completion. Current location in the dissertation is indicated by the flow chart in Figure 6-18.

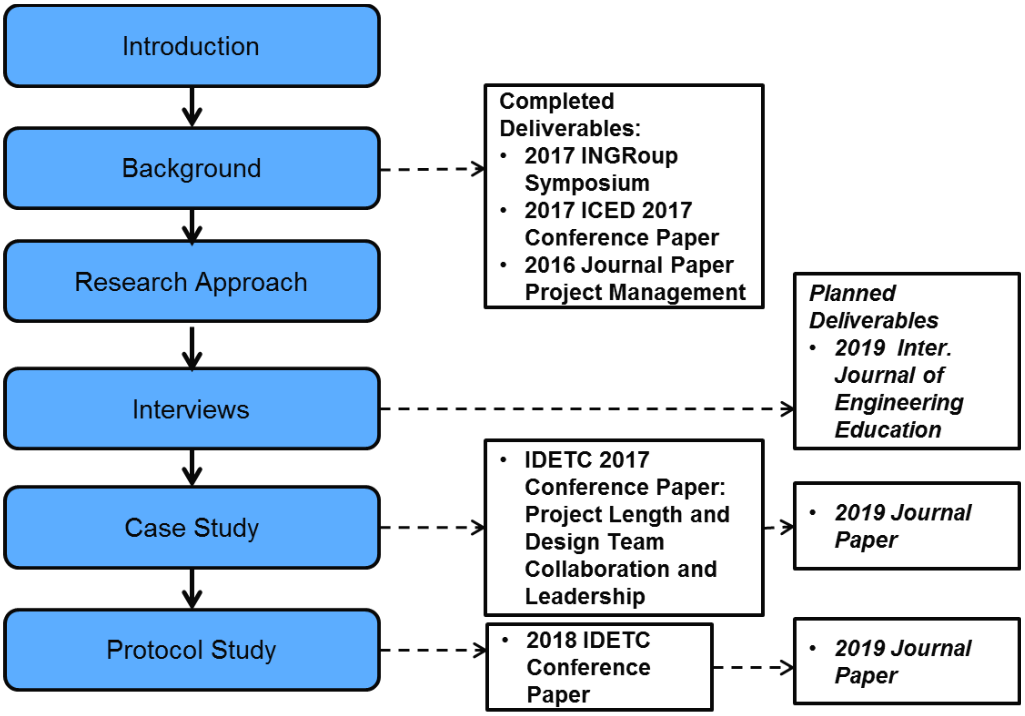

Figure 6-18. Dissertation roadmap.

CHAPTER SEVEN: CONCLUSIONS

This chapter will review the conclusions and present recommended areas for further research. Figure 7-1 reviews the timeline of the research included in this dissertation and the deliverables accomplished and projected.

Activity	F 15	S 16	Su 16	F 16	S 17	Su 17	F 17	S 18	Su 18	F 18	S 19
Background development		**J**				**C** **C**					
Interview											**J**
• Development											
• Collection											
• Analysis											
Case Study											
• Preliminary Study					**C**						**J**
• Case 1											
• Case 2											
Protocol Study									**C**		**J**
• Development											
• Pilot											
• Primary Study											
Dissertation											
Deliverables found on timeline: C=Conference paper or abstract J=Journal Paper											

Figure 7-1. Review of Research Timeline

Interviews established faculty perceptions of leadership in undergraduate engineering design teams. Case studies examined engineering design team leadership structures in capstone teams across the lifecycle of the project team and focused on perceived leader-follower relationships and communications between team members in teams of varying composition and projects of varied lengths. Protocol studies were then used to observe functional leadership behaviors directly during conceptual design through team function modeling. This breadth of research methods was used to triangulate results, capitalize on each method's strengths, and gain understanding of leadership both across the project lifecycle and in a focused activity.

7.1 Research Question 1: Emergence

Research question one is reviewed in Table 7-1. This research question was addressed in each of three research methods.

Table 7-1. Research Question 1: Emergence.

RQ 1: How does leadership emerge in engineering design teams?

Both formal and informal leadership structures exist in student design teams. Formal structures are commonly established by the team members with varied degrees of prompting and instruction from faculty. In some cases, faculty may also assign student leaders based on limited observation of the members and early team interactions. These formal structures commonly remain consistent throughout the project unless challenges require changes; although leadership roles may be rotated to provide leadership experience to more students.

Informal leadership structures are also established in these projects. The case studies clearly established the perceived leader-follower relationships in the ten-member aerospace teams. Faculty members indicated that informal relationships were also common and significant in smaller Capstone teams. The density and composition of these structures do vary throughout the project based on project requirements and other challenges. The final case study team experienced an increase in density in the early project stages as the team transited from conceptual to embodiment design and gained experience and familiarity with team members. This perceived density then became more centralized near the conclusion of the project during detailed design and manufacturing. This was also reflected in the communication networks.

During the short and focused function modeling sessions, leaders emerged rapidly and generally remained consistent throughout the project. A high level of leadership activity occurred in these teams without formal structures. However, the level of familiarity and commonality of design education and training appeared to affect the specific transition leadership functions performed. Relational activities were the least frequently observed behaviors in both the case studies and protocol studies. This is consistent with parallel leadership research [94].

7.2 Research Question 2: Distribution

Research question two is provided in Table 7-2. This research question was pursued to gain understanding of the distribution of leadership functional behaviors across the members of novice engineering design teams.

Table 7-2. Research Question 2: Distribution

RQ 2: How are leadership functions distributed within the engineering design team?

Informal leadership functions are distributed across the student design teams participating in this research. The density of the structures is indicative of this distribution. While the leaders most frequently performing specific functions do often recur across the observation periods in the protocol studies, other members were observed to perform these functions both at the highest rates and lower frequencies. Again, this is consistent with faculty perceptions of informal leadership roles and behaviors.

Case studies quantified the distribution of these functions across the selected design teams. This distribution is indicated by both the distribution of the functions and the centrality of leaders to these leader-follower relationships.

7.3 Research Question 3: Composition

Research Question three is below in Table 7-3. This question addressed the composition of design teams and its impact on leadership structures.

Table 7-3. Research Question 3: Composition.

RQ 3: How does composition (size, organization) impact leadership structure (position and functional distribution) in engineering design teams?

Composition was addressed in the interview: primarily in the first portion of the interview. Faculty provided their approach to composing teams to include the choice of size based on desired group dynamics and the scope and scale of the design problem. This composition impacts the development of leadership and teamwork skills. It also impacted the complexity of leadership and communication structures in case study teams: with larger multiteam systems experiencing this increased complexity. A single instance of variation in protocol study team size also suggests a structural parity in three-member teams that was not observed in four-member teams.

7.4 Summary and Recommended Research Areas

This understanding of leadership emergence and distribution in design teams provides opportunities for study and development in many areas. These topics relate to both distribution and emergence in many cases.

7.4.1 Leadership development

All research efforts supported the concept that all student designers were involved in leadership within their design teams. While every student may not have the opportunity to lead his or her Capstone design project, every student designer participates informally in the leadership functions required by the team and its members. This provides motivation to offer leadership education and opportunities to develop leadership skills. Novice engineers can benefit from meaningful feedback during team design and leadership opportunities. However, faculty often have limited opportunities to observe students when they are engaged in team tasks. Primary interactions tend to occur during review activities, and while these are valuable, this limits the ability to assess leadership and teamwork.

Providing quality feedback to assist in mentoring students and developing their leadership skills would be supported by the ability to assess leader-follower interactions paired with effective interventions. An instrument similar to the case study survey tool could serve to assist in assessing leadership and communication processes within teams. This could particularly benefit instructors advising larger and distributed teams. The intent would not be to serve as a grading tool, but to understand the leadership dynamics within the team. Instructors also would require effective interventions (training tools) to assist with providing feedback to team members.

Research is needed to assess intervention effectiveness. Specific research questions could be structured:

- Does understanding of leadership and communication networks assist faculty advisors in developing student leadership skills?

- Does leadership training develop leadership skills and understanding in engineering design students?
- How does leadership network density impact design quality and novelty in specified design activities?

7.4.2 Faculty and student perceptions and observations

Faculty perceptions were obtained through the leadership interviews while student leadership perception was obtained in case studies. The protocol studies provided observations of the distribution and emergence of leadership behaviors in student design teams. The information obtained from each study was not equivalent, however there are similarities and differences in observations that merit consideration. Relational leadership functions were commonly addressed by faculty, however, the density of relational leadership functions in case studies was lower than transition and action functions. Relational functions were also less common in protocol observations.

Sensemaking was prominent in observations compared to faculty responses. One possible explanation is that faculty are not able to observe the designers performing many team design activities that must be completed outside of the classroom. Faculty perspective is more focused on boundary management, possibly due to their role as external leaders. Capstone instructors could emphasize the leadership skills that are commonly needed but may not be observed in review meetings. This could assist in developing novice engineers and improving teamwork skills. Students could also benefit from instruction on relational functions, since these are less frequently observed. Boundary management instruction could be provided to develop student skills and allow them to benefit from faculty experience and perspective on this function.

Research is warranted to assess the effectiveness of instruction on these topics.

- Does training on boundary management improve novice engineers' ability to manage interactions?
- Does relational function emphasis or instruction improve teamwork development and project team performance in novice design teams?

7.4.3 Capstone team composition

The research shows that team composition factors such as size, organization, and distribution impact student leadership opportunities within the design team. These factors merit exploration:

- How does team size impact leadership development and participation in novice engineers?
- How do multi-disciplinary design projects impact acquisition of leadership skills and other learning objectives?

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APPENDICES

APPENDIX A. PRELIMINARY STUDY SURVEY RESULTS

Figure A- 1 summarizes the survey results from the Spring 2016 case study (5.2). This study surveyed one-semester and one-year (two academic semesters) teams on their leadership structures and communication mode and frequency. The final questions covered the group dynamic of acceptance. The first column includes specific answers; the second column provides the question. The remaining two columns are the results for one-semester and two-semester teams surveyed.

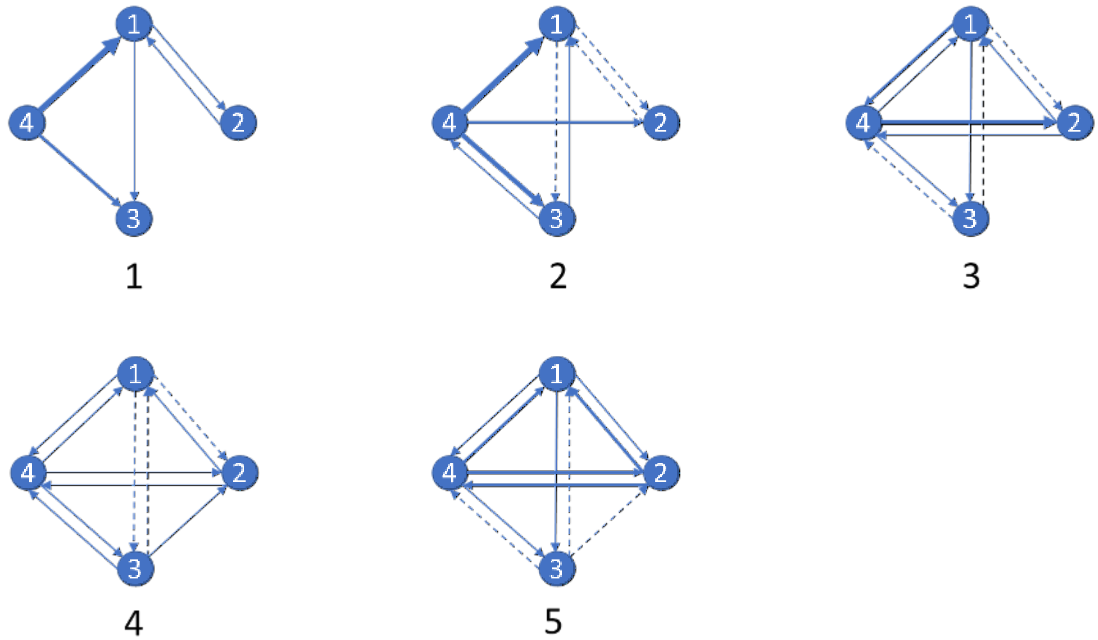
	Description	1 Semester	1 Year
1 (%Yes)	Does your group have an established leader (Y/N)?	52.17%	100.00%
2(%Selected by vote)	Was your group leader: A) Assigned, B) Selected by Group, C) Assumed	36.25%	100.00%
3_Design*	What types of decisions does the group make by vote?	10	2
3_None		10	0
3_Budget		2	0
3_Admin		3	5
3_Everything		2	0
4_Design	What types of decision are made by consensus (agreement by all)?	5	3
4_None		2	1
4_Budget		1	0
4_Admin		5	1
4_Everything		9	1
5_Design	What types of decision are made by the group's leader?	2	2
5_None		13	1
5_Budget		3	0
5_Admin		4	4
5_Everything		1	0
6	On average, over the last month, how often did you communicate with other team members:		
6a(Avg)	In scheduled meetings of entire project team?	9.95	7.6
6b(Avg)	In scheduled meetings of sub-group	8.65	4.4
6c(Avg)	Scheduled one-on-one meetings?	4.19	5.2
6d(Avg)	Non-scheduled, impromptu, meetings?	3.76	3.6
6(Sum of Avg's)		26.55	20.8
7	When you communicate, how long does the discussion last:		
7a(Avg)	In scheduled meetings of entire project team?	1.52	1.1
7b(Avg)	In scheduled meetings of sub-group?	1.31	0.65
7c(Avg)	Scheduled one-on-one meetings?	0.39	1.38
7d(Avg)	Non-scheduled, impromptu, meetings?	0.64	0.45
	Total Meeting Time (communication time)	30.49	20.13
	How often (in the last month) were there misunderstandings in communication with team members:		
8a(Avg)	during in-person (collocated) meetings?	1	1.2
8b(Avg)	during technology assisted meetings (members at different locations)?	1	2.8
9(individual)	Are design problems solved individually or as a group?	2	0
9(group)		12	1
9(both)		9	4
10	How accepting are your group members to your opinion on problems (mark on the line where appropriate)?	4.22	4.38
11	School familiarity	63.22	20.00
12	Social familiarity	52.17	20.00
# Survey Responses		23.00	5.00
Response Rate		95.83	41.67

Figure A- 1. Survey results from Spring 2016 Case Study

APPENDIX B. PROTOCOL STUDY ADJACENCY MATRICES AND NETWORKS

Figure A- 2 through Figure A- 10 provide leadership network representations for the protocol study discussed in Chapter Six. The networks are depicted for each of the teams of populations A, and B. Each individual network is numbered (one through five) and represents one quintile of the function modeling activity. A discussion of the temporal representation is provided in 6.3.3. Rankings are also provided for out degree centrality, first row; and in degree centrality, second row. Out degree centrality for these networks represents the centrality of the designer for leadership behaviors, while in degree centrality represents the centrality for follower behaviors. Weighted out degree centrality is equivalent to the total number of observed leadership behaviors for the specified designer in the given quintile. Weighted in degree centrality is the total number of observed follower behaviors for the specified designer in that quintile. Quintiles are represented by Roman numerals on the top of the tables.

Figure A- 2 is the network representation for Team A.1. Designer four begins as the most active in leadership behaviors as determined by number of occurrences. He remains the most central designer for the first four of the five quintiles. No leadership behaviors are observed between designers two and three until the fourth quintile.



Weighted Out Degree Centrality

	I	II	III	IV	V
1	2	0	3	1	3
2	1	0	1	1	4
3	0	2	0	2	0
4	6	9	5	3	4

Out Degree Centrality

	I	II	III	IV	V
1	2	0	2	1	3
2	1	0	1	1	2
3	0	2	0	2	0
4	2	3	3	3	2

Rank Weighted

Des	Q1	Q2	Q3	Q4	Q5
1	2	3	2	3	3
2	3	3	3	3	1
3	4	2	4	2	4
4	1	1	1	1	1

Rank Unweighted

Des	Q1	Q2	Q3	Q4	Q5
1	1	3	2	3	1
2	3	3	3	3	2
3	4	2	4	2	4
4	1	1	1	1	2

Weighted In Degree Centrality

	I	II	III	IV	V
1	5	5	1	1	4
2	1	2	3	2	3
3	3	3	2	1	1
4	0	1	3	3	3

In degree Centrality

	I	II	III	IV	V
1	2	2	1	1	2
2	1	1	1	2	2
3	2	1	2	1	1
4	0	1	2	3	2

Rank Weighted in

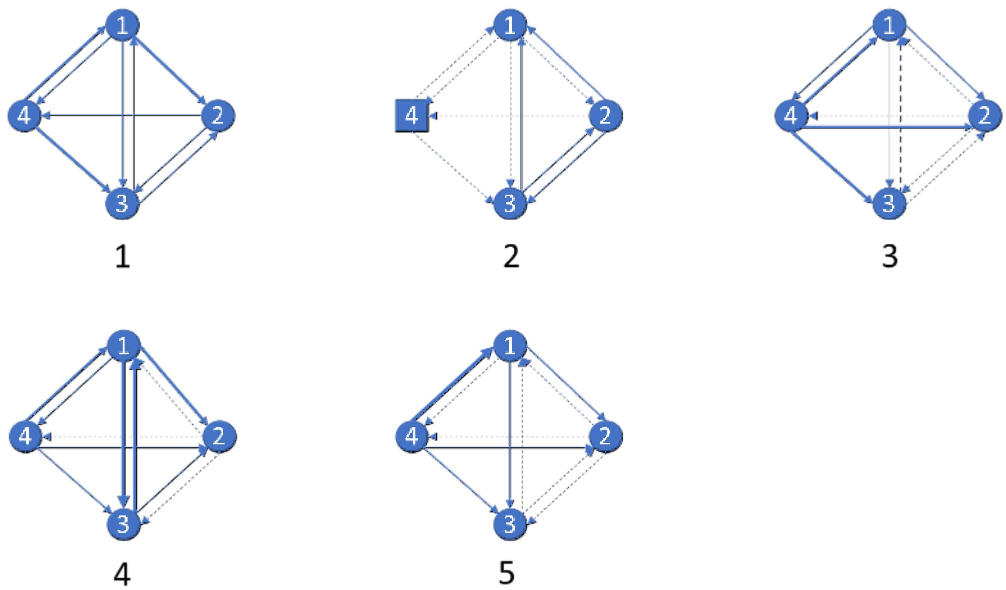
Des	Q1	Q2	Q3	Q4	Q5
1	1	1	4	3	1
2	3	3	1	2	2
3	2	2	3	3	4
4	4	4	1	1	2

Rank Unweighted in

Des	Q1	Q2	Q3	Q4	Q5
1	1	1	3	3	1
2	3	2	3	2	1
3	1	2	1	3	4
4	4	2	1	1	1

Figure A- 2. Team A.1 leadership network representation and activity rankings.

Figure A- 3is the leadership network representation for Team A.2. Designers one and four hold the first ranking for number of occurrences and unweighted centrality in quintiles one, three, four and five. In the second quintile, designer four is not engaged in the network as indicated by the square node [172], and designers two and three are most active and central.



Weighted Out Degree Centrality

	I	II	III	IV	V
1	4	0	3	6	2
2	2	2	0	0	0
3	2	2	0	4	0
4	4	0	6	4	5

Out Degree Centrality

	I	II	III	IV	V
1	3	0	3	3	2
2	2	2	0	0	0
3	2	2	0	2	0
4	2	0	3	3	3

Rank Weighted

Des	Q1	Q2	Q3	Q4	Q5
1	1	3	2	1	2
2	3	1	3	4	3
3	3	1	3	2	3
4	1	3	1	2	1

Rank Unweighted

Des	Q1	Q2	Q3	Q4	Q5
1	1	3	1	1	2
2	2	1	3	4	3
3	2	1	3	3	3
4	2	3	1	1	1

Weighted In Degree Centrality

	I	II	III	IV	V
1	3	2	2	5	3
2	3	1	3	4	2
3	4	1	3	4	2
4	2	0	1	1	0

In degree Centrality

	I	II	III	IV	V
1	2	2	1	2	1
2	2	1	2	3	2
3	3	1	2	2	2
4	2	0	1	1	0

Rank Weighted in

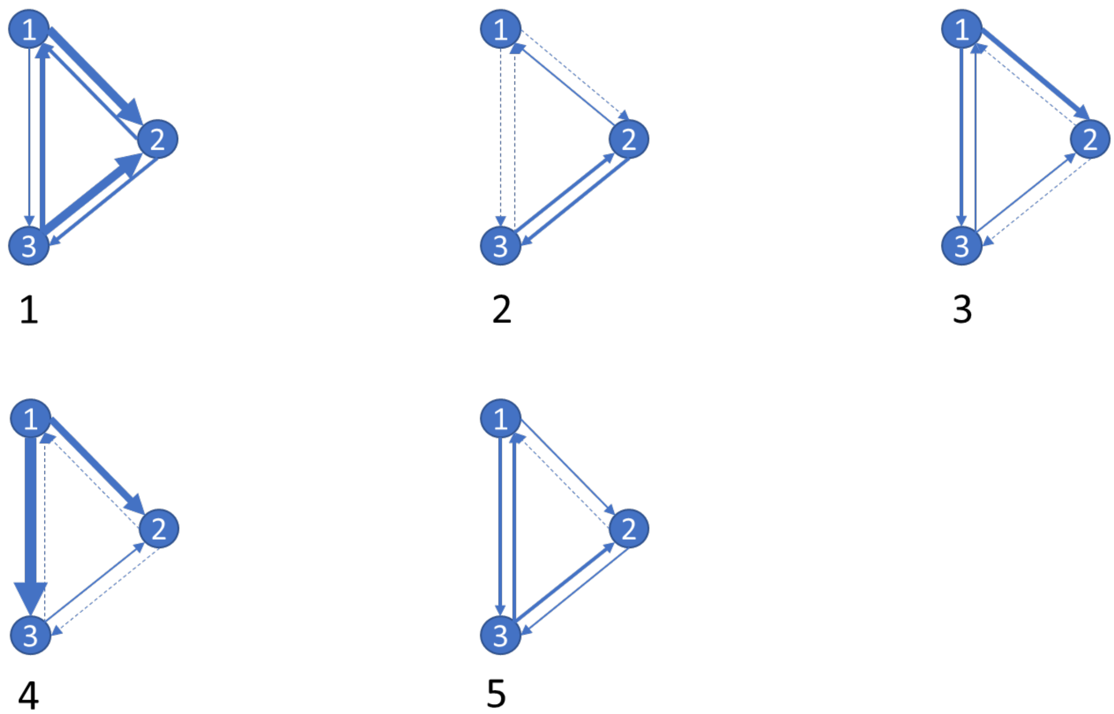
Des	Q1	Q2	Q3	Q4	Q5
1	2	1	3	1	1
2	2	2	1	2	2
3	1	2	1	2	2
4	4	4	4	4	4

Rank Unweighted in

Des	Q1	Q2	Q3	Q4	Q5
1	2	1	3	2	3
2	2	2	1	1	1
3	1	2	1	2	1
4	2	4	3	4	4

Figure A- 3. Team A.2 leadership network representation and leadership activity rankings.

Figure A- 4 is the leadership network representation for Team A.3. This three-member team has a relatively flat leadership network. Activity is highest in quintile one with a fully dense network.



Weighted Out Degree Centrality

	I	II	III	IV	V
1	6	0	5	10	3
2	4	3	0	0	1
3	8	2	2	1	4

Out Degree Centrality

	I	II	III	IV	V
1	2	0	2	2	2
2	2	2	0	0	1
3	2	1	2	1	2

Rank Weighted

Des	Q1	Q2	Q3	Q4	Q5
1	2	3	1	1	2
2	3	1	3	3	3
3	1	2	2	2	1

Rank Unweighted

Des	Q1	Q2	Q3	Q4	Q5
1	1	3	1	1	1
2	1	1	3	3	3
3	1	2	1	2	1

Weighted In Degree Centrality

	I	II	III	IV	V
1	5	1	1	0	2
2	10	2	4	5	3
3	3	2	2	6	3

In degree Centrality

	I	II	III	IV	V
1	2	1	1	0	1
2	2	1	2	2	2
3	2	1	1	1	2

Rank Weighted in

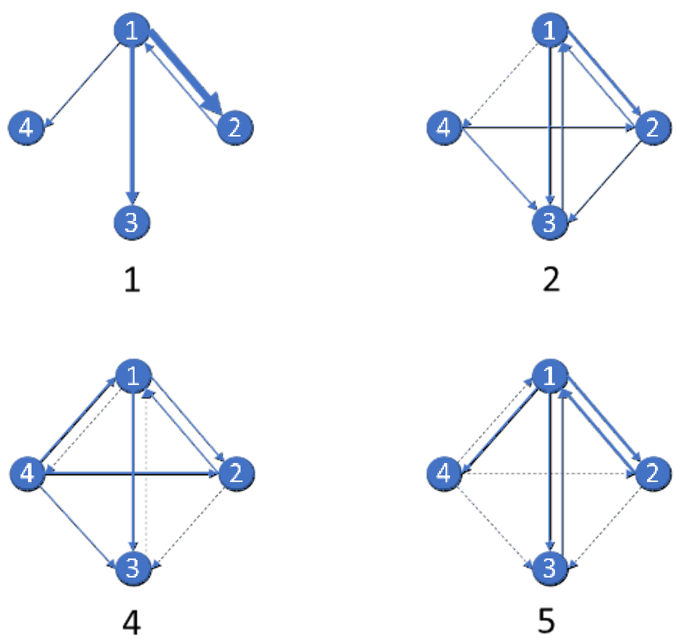
Des	Q1	Q2	Q3	Q4	Q5
1	2	3	3	3	3
2	1	1	1	2	1
3	3	1	2	1	1

Rank Unweighted in

Des	Q1	Q2	Q3	Q4	Q5
1	1	1	2	3	3
2	1	1	1	1	1
3	1	1	2	2	1

Figure A- 4. Team A.3 leadership network representation and leadership activity rankings.

Figure A- 5 is the leadership network representation for Team A.4. Designer one establishes the first ranking for occurrences and centrality in the first quintile and holds or shares the first ranking in four of the five quintiles.



Weighted Out Degree Centrality

	I	II	III	IV	V
1	9	4	9	3	6
2	1	1	0	1	2
3	0	1	0	0	1
4	0	2	2	5	0

Out Degree Centrality

	I	II	III	IV	V
1	3	2	3	2	3
2	1	1	0	1	1
3	0	1	0	0	1
4	0	2	2	3	0

Rank Weighted

Des	Q1	Q2	Q3	Q4	Q5
1	1	1	1	2	1
2	2	3	3	3	2
3	3	3	3	4	3
4	3	2	2	1	4

Rank Unweighted

Des	Q1	Q2	Q3	Q4	Q5
1	1	1	1	2	1
2	2	3	3	3	2
3	3	3	3	4	2
4	3	1	2	1	4

Weighted In Degree Centrality

	I	II	III	IV	V
1	1	1	1	3	3
2	5	3	5	3	2
3	3	4	4	3	2
4	1	0	1	0	2

In degree Centrality

	I	II	III	IV	V
1	1	1	1	2	2
2	1	2	2	2	1
3	1	3	1	2	1
4	1	0	1	0	1

Rank Weighted in

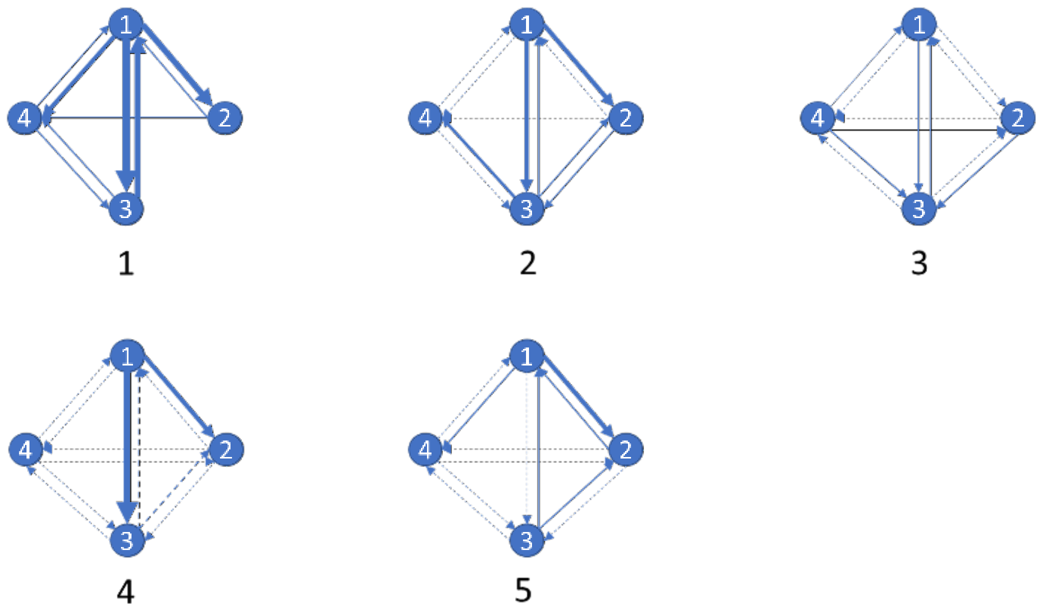
Des	Q1	Q2	Q3	Q4	Q5
1	3	3	3	1	1
2	1	2	1	1	2
3	2	1	2	1	2
4	3	4	3	4	2

Rank Unweighted in

Des	Q1	Q2	Q3	Q4	Q5
1	1	3	2	1	1
2	1	2	1	1	2
3	1	1	2	1	2
4	1	4	2	4	2

Figure A- 5. Team A.4 leadership network representation and leadership activity rankings.

Figure A- 6 is the leadership network representation for Team A.5. Designer one holds or shares the first ranking in leadership occurrences for four quintiles (including the first) and centrality for three of five. Designer one has only one observed leadership behavior in the third quintile.



Weighted Out Degree Centrality

	I	II	III	IV	V
1	12	6	1	8	4
2	2	1	1	0	1
3	5	4	1	0	2
4	2	0	3	1	0

Out Degree Centrality

	I	II	III	IV	V
1	3	2	1	2	2
2	2	1	1	0	1
3	2	3	1	0	2
4	2	0	3	1	0

Rank Weighted

Des	Q1	Q2	Q3	Q4	Q5
1	1	1	2	1	1
2	3	3	2	3	3
3	2	2	2	3	2
4	3	4	1	2	4

Rank Unweighted

Des	Q1	Q2	Q3	Q4	Q5
1	1	2	2	1	1
2	2	3	2	3	3
3	2	1	2	3	1
4	2	4	1	2	4

Weighted In Degree Centrality

	I	II	III	IV	V
1	6	1	2	0	2
2	4	4	1	3	4
3	6	4	3	6	0
4	5	2	0	0	1

In degree Centrality

	I	II	III	IV	V
1	3	1	2	0	2
2	1	2	1	1	2
3	2	2	3	2	0
4	3	1	0	0	1

Rank Weighted in

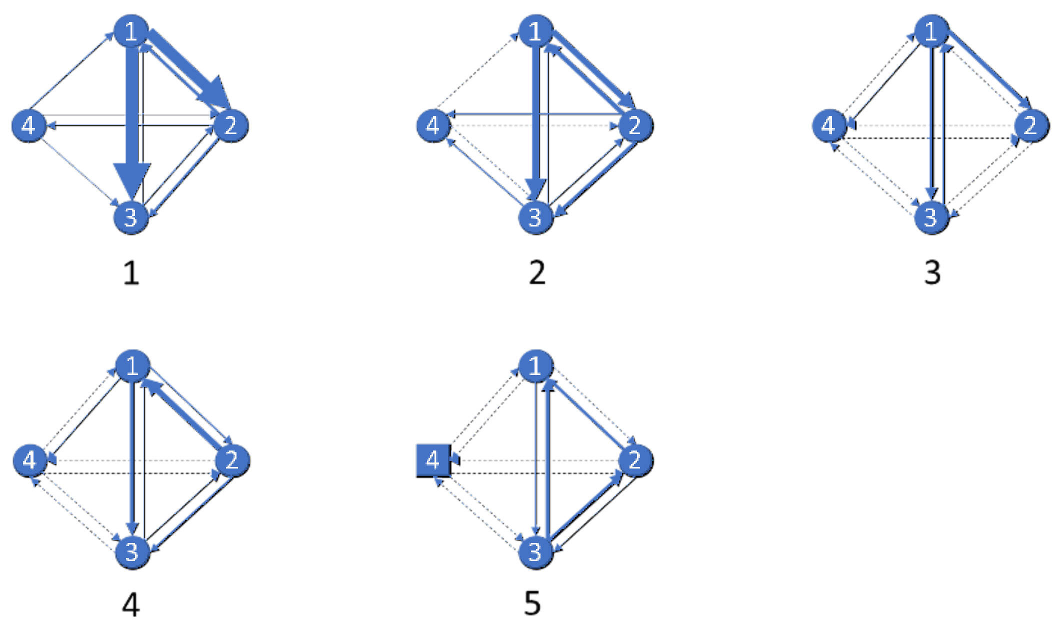
Des	Q1	Q2	Q3	Q4	Q5
1	1	4	2	3	2
2	4	1	3	2	1
3	1	1	1	1	4
4	3	3	4	3	3

Rank Unweighted in

Des	Q1	Q2	Q3	Q4	Q5
1	1	3	2	3	1
2	4	1	3	2	1
3	3	1	1	1	4
4	1	3	4	3	3

Figure A- 6. Team A.5 leadership network representation and leadership activity rankings.

Figure A- 7 is the leadership network representation for Team B.1. Designer one ranks first in occurrences for the first three quintiles; but, does not hold the highest unweighted centrality until the third quintile because of no prior observed leadership directed to designer four.



Weighted Out Degree Centrality

	I	II	III	IV	V
1	15	9	7	5	1
2	5	7	0	6	3
3	2	3	2	2	6
4	3	0	0	0	0

Out Degree Centrality

	I	II	III	IV	V
1	2	2	3	3	1
2	3	3	0	2	2
3	2	3	1	2	2
4	3	0	0	0	0

Rank Weighted

Des	Q1	Q2	Q3	Q4	Q5
1	1	1	1	2	3
2	2	2	3	1	2
3	4	3	2	3	1
4	3	4	3	4	4

Rank Unweighted

Des	Q1	Q2	Q3	Q4	Q5
1	3	3	1	1	3
2	1	1	3	2	1
3	3	1	2	2	1
4	1	4	3	4	4

Weighted In Degree Centrality

	I	II	III	IV	V
1	4	4	2	5	5
2	9	5	3	2	3
3	11	8	3	5	2
4	1	2	1	1	0

In degree Centrality

	I	II	III	IV	V
1	3	2	1	2	2
2	3	2	1	2	1
3	3	2	1	2	2
4	1	2	1	1	0

Rank Weighted in

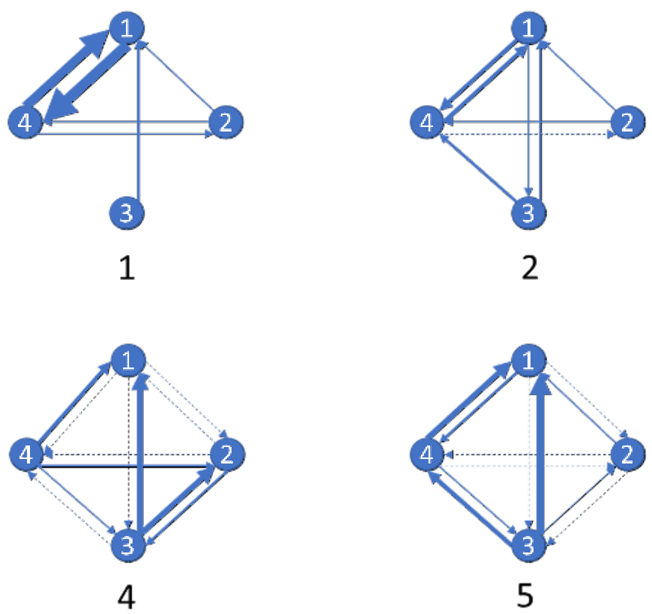
Des	Q1	Q2	Q3	Q4	Q5
1	3	3	3	1	1
2	2	2	1	3	2
3	1	1	1	1	3
4	4	4	4	4	4

Rank Unweighted in

Des	Q1	Q2	Q3	Q4	Q5
1	1	1	1	1	1
2	1	1	1	1	3
3	1	1	1	1	1
4	4	1	1	4	4

Figure A- 7. Team B.1 leadership network representation and leadership activity rankings.

Figure A- 8 is the leadership network representation for Team B.2.



Weighted Out Degree Centrality

	I	II	III	IV	V
1	7	4	7	0	2
2	2	2	0	2	1
3	2	4	2	8	9
4	7	3	1	6	5

Out Degree Centrality

	I	II	III	IV	V
1	1	2	2	0	1
2	2	2	0	1	1
3	1	2	2	2	3
4	2	1	1	3	2

Rank Weighted

Des	Q1	Q2	Q3	Q4	Q5
1	1	1	1	4	3
2	3	4	4	3	4
3	3	1	2	1	1
4	1	3	3	2	2

Rank Unweighted

Des	Q1	Q2	Q3	Q4	Q5
1	3	1	1	4	3
2	1	1	4	3	3
3	3	1	1	2	1
4	1	4	3	1	2

Weighted In Degree Centrality

	I	II	III	IV	V
1	9	6	1	7	10
2	1	0	4	6	1
3	0	1	0	3	1
4	8	6	5	0	5

In degree Centrality

	I	II	III	IV	V
1	3	3	1	2	3
2	1	0	2	2	1
3	0	1	0	2	1
4	2	3	2	0	2

Rank Weighted in

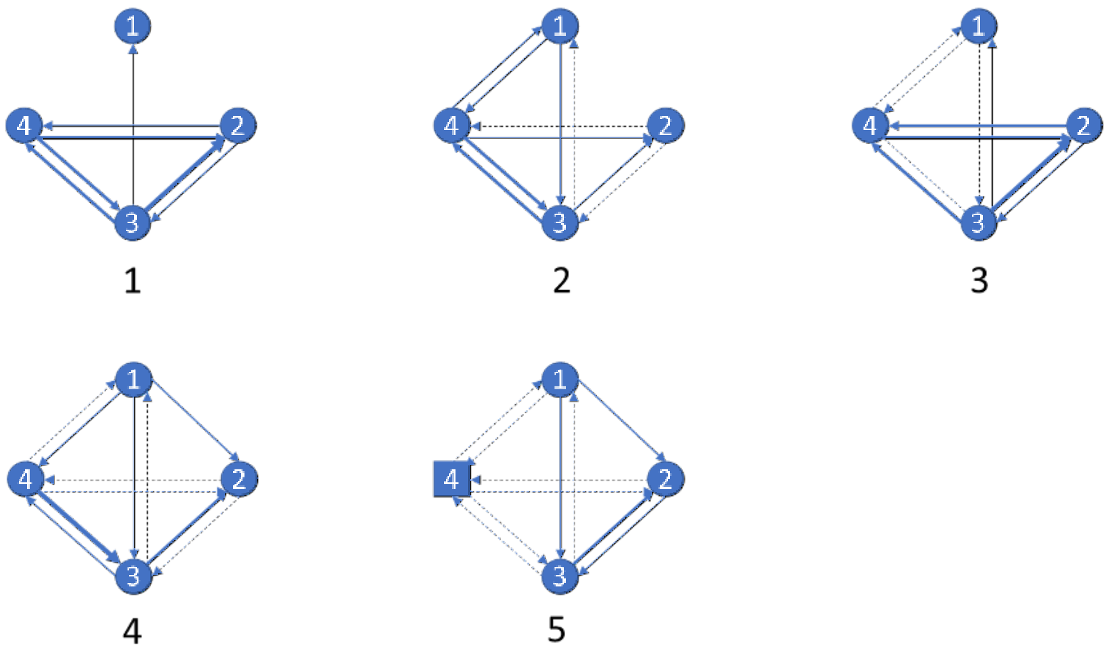
Des	Q1	Q2	Q3	Q4	Q5
1	1	1	3	1	1
2	3	4	2	2	3
3	4	3	4	3	3
4	2	1	1	4	2

Rank Unweighted in

Des	Q1	Q2	Q3	Q4	Q5
1	1	1	3	1	1
2	3	4	1	1	3
3	4	3	4	1	3
4	2	1	1	4	2

Figure A- 8. Team B.2 leadership network representation and leadership activity rankings.

Figure A- 9 is the leadership network representation for Team B.3. Designer three consistently holds a centrality ranking of first or second. Designer one is only connected as a follower in the first and third quintiles.



Weighted Out Degree Centrality

	I	II	III	IV	V
1	0	2	0	3	2
2	2	0	3	0	1
3	6	3	6	3	2
4	4	4	2	3	0

Out Degree Centrality

	I	II	III	IV	V
1	0	2	0	3	2
2	2	0	2	0	1
3	3	2	3	2	1
4	2	3	1	1	0

Rank Weighted

Des	Q1	Q2	Q3	Q4	Q5
1	4	3	4	1	1
2	3	4	2	4	3
3	1	2	1	1	1
4	2	1	3	1	4

Rank Unweighted

Des	Q1	Q2	Q3	Q4	Q5
1	4	2	4	1	1
2	2	4	2	4	2
3	1	2	1	2	2
4	2	1	3	3	4

Weighted In Degree Centrality

	I	II	III	IV	V
1	1	1	1	0	0
2	5	2	5	3	3
3	3	3	1	4	2
4	3	3	4	2	0

In degree Centrality

	I	II	III	IV	V
1	1	1	1	0	0
2	2	2	2	2	2
3	2	2	1	2	2
4	2	2	2	2	0

Rank Weighted in

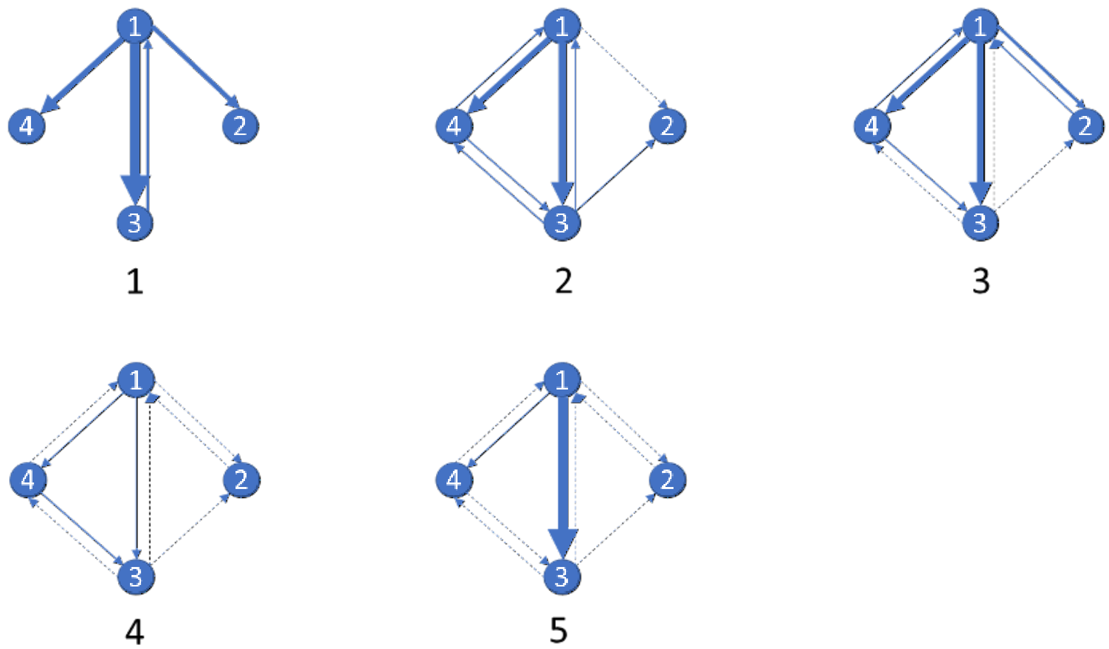
Des	Q1	Q2	Q3	Q4	Q5
1	4	4	3	4	3
2	1	3	1	2	1
3	2	1	3	1	2
4	2	1	2	3	3

Rank Unweighted in

Des	Q1	Q2	Q3	Q4	Q5
1	4	4	3	4	3
2	1	1	1	1	1
3	1	1	3	1	1
4	1	1	1	1	3

Figure A- 9. Team B.3 leadership network representation and leadership activity rankings.

Figure A- 10 is the leadership network representation for Team B.4. Designer one establishes centrality in the first quintile and maintains it for four of five periods. She also maintains the highest number of occurrences throughout.



Weighted Out Degree Centrality

	I	II	III	IV	V
1	13	9	11	2	7
2	0	0	1	0	0
3	2	3	0	0	0
4	0	2	2	1	0

Out Degree Centrality

	I	II	III	IV	V
1	3	2	3	2	2
2	0	0	1	0	0
3	1	3	0	0	0
4	0	2	2	1	0

Rank Weighted

Des	Q1	Q2	Q3	Q4	Q5
1	1	1	1	1	1
2	3	4	3	3	2
3	2	2	4	3	2
4	3	3	2	2	2

Rank Unweighted

Des	Q1	Q2	Q3	Q4	Q5
1	1	2	1	1	1
2	3	4	3	3	2
3	2	1	4	3	2
4	3	2	2	2	2

Weighted In Degree Centrality

	I	II	III	IV	V
1	2	2	2	0	0
2	3	1	2	0	0
3	6	6	6	2	6
4	4	5	4	1	1

In degree Centrality

	I	II	III	IV	V
1	1	2	2	0	0
2	1	1	1	0	0
3	1	2	2	2	1
4	1	2	1	1	1

Rank Weighted in

Des	Q1	Q2	Q3	Q4	Q5
1	4	3	3	3	3
2	3	4	3	3	3
3	1	1	1	1	1
4	2	2	2	2	2

Rank Unweighted in

Des	Q1	Q2	Q3	Q4	Q5
1	1	1	1	3	3
2	1	4	3	3	3
3	1	1	1	1	1
4	1	1	3	2	1

Figure A- 10. Team B.4 leadership network representation and leadership activity rankings.

APPENDIX C. CODING MANUAL [94]

Leadership in engineering Design Teams: Coding manual

Clemson Engineering Design Applications Research (CEDAR)

Clemson University Department of Mechanical Engineering

Spring 2018

Version 4

Updated: Wednesday, March 7, 2018

TABLE OF CONTENTS

CODING INSTRUCTIONS

1. Choose a recorded session to code.
   a. Use the coding tracking form to identify what sessions need to be coded.
2. Open the video you are going to be coding.
3. Open a new copy of the excel coding template.
   a. Fill in the header with the information pertaining to the video.
   b. Your name as observer.
   c. The date you are analyzing the video.
   d. The team you are observing.
   e. The date the team was observed.
   f. The source video file name.
4. Save the Excel coding file.
   a. IF the video is a team meeting save as YYYY.MM.DD – Team X Week X.
   b. IF the video is a design review save as YYYY.MM.DD – Team X DR X.
   c. Save a copy of the coding file to the Google Drive and save a personal copy.
5. Review all the leadership behaviors in this manual prior to coding a session.
6. Watch the recorded session all the way through to become familiar with the activities in the session.
7. Watch the recorded session a second time, and code all occurrences of functional leadership in the coding tool (see example of coding tool section).
   a. Record the observed leadership function (Acronym; see list in the Coding Acronyms and Shortcuts and definitions in Definitions of Leadership Functions).
   b. Record the design space the team was exploring when the leadership behavior occurred (see list in Coding Acronyms and Shortcuts and definitions in Engineering Design Space Definitions).
   c. Record the design activity that was occurring when the leadership behavior occurred (see list in Coding Acronyms and Shortcuts and definitions in Engineering Design Activities Definitions).
   d. Record the person performing the behavior with an L.
   e. Record the team members who were influenced with an F.
   f. Record the team members who are absent from the room with an A.

   g. Record the <u>start time</u> of the behavior.

   h. Record the <u>end time</u> of the behavior.

   i. <u>Type out the activity/behavior you coded in the comments section</u>.

   j. Note that the grey columns of the coding tool spreadsheet auto-populate.

8. Refer to the definitions and examples in this manual for assistance determining how to code leadership behaviors.

   a. Note that no leadership behavior can occur without a paired follower behavior, this is because in order for leadership to take place, there must be influence on the team. This influence is observed as follower behavior.

   b. Identify each instance of leadership behavior independently of other team members, teams, recordings, or other observations of leadership (do not compare to any other recording).

   c. Do not consider the quality of the behavior being performed. For example, if Person A creates a strategy and plan for the semester, however, it does not align with the teams' goals, you still record this as a leadership behavior if team members begin to carry out the plan.

   d. Understand the examples listed in this coding manual are not a complete set. Behaviors will occur that are not listed as examples. Use the examples and the definitions of the leadership functions to identify what leadership function occurred.

9. Be sure to record any comments or questions with a timestamp so that they can be identified later.

10. Save the coding file at least once every 10 minutes.

11. Record an entire session at once.

   a. Update the tracking sheet upon completion of coding a recording.

   b. If you cannot code a recording to completion, update the tracking sheet and make a note of the time you left off at so that you do not have to search for it when you return to code the rest of the recording.

12. If possible, ask questions as often as possible. If possible see CEDAR students in EIB 134/136. If it's not possible to meet with CEDAR students, please get in contact through email.

LIST OF LEADERSHIP FUNCTIONS

Task Oriented

- Compose Team
- Define Mission
- Establish Expectations and Goals
- Structure and Plan
- Train and Develop
- Sensemaking
- Provide Feedback
- Monitor and Guide Team Tasks
- Manage Team Boundaries
- Challenging the Team
- Perform Team Task
- Solve Problems
- Provide Resources
- Encourage Team Self-Management
- Support Social Climate

Relational Oriented

- Consideration
- Empowerment

TASK VS. RELATIONAL ORIENTED DEFINED

Identifying whether a behavior is relational or task oriented will help determine what leadership function occurred.

Task Oriented

Task oriented leadership functions primarily deal with the project, work, and tasks the team does throughout its lifetime. These functions include, composing the team, defining the mission, establishing goals and expectations, structure and planning, and providing feedback to name some (the complete list is available on page 207). Task oriented behavior also focusing on setting and monitoring standards for performance and monitoring the team's performance throughout the project [173].

Relational Oriented

Relational oriented behaviors focus on the interpersonal skills and relationships amongst the team. These include consideration and empowerment. Consideration deals with always being friendly and approachable and making sure that all the team members are being treated equally and well. Empowerment includes improving the confidence and moral of the team members by providing positive reinforcement and offering opportunities for team members to improve their skills and gain confidence [173].

CODING ACRONYMS AND SHORTCUTS

Table A- 1. Acronyms for leadership functions.

Function	Acronym
Compose Team	COMP
Define Mission	DM
Establish Expectations and Goals	EG
Structure and Plan	SP
Train and Develop	TD
Sensemaking	SM
Provide Feedback	PF
Monitor and Guide Team Tasks	MG
Manage Team Boundaries	MB
Challenging the Team	CT
Perform Team Task	PT
Solve Problems	SPS
Provide Resources	PR
Encourage Team Self-Management	ESM
Support Social Climate	SSC
Consideration	C
Empowerment	E

Table A- 2. Acronyms for individuals performing the behaviors.

Person Performing Behavior	Acronym
Leader	L
Follower	F

Table A- 3. Engineering Design Spaces.

Engineering Design Spaces
Problem Space
Solution Space
Project Space

Table A- 4. Engineering Design Activities.

Engineering Design Activities
Synthesis
Analysis
Decision Making
Transformation
Communication

CODING CHEAT SHEET / TEAM MEMBER IDENTIFICATION

Table A- 5. Functions and abbreviations.

Function	Abrv.
Compose Team	COMP
Define Mission	DM
Establish Expectations and Goals	EG
Structure and Plan	SP
Train and Develop	TD
Sensemaking	SM
Provide Feedback	PF
Monitor and Guide Team Tasks	MG
Manage Team Boundaries	MB
Challenging the Team	CT
Perform Team Task	PT
Solve Problems	SPS
Provide Resources	PR
Encourage Team Self-Management	ESM
Support Social Climate	SSC
Consideration	C
Empowerment	E

Table A- 6. Team A identification key.

Team A		
Person A		
Person B		
Person C		
Person D		

Table A- 7. Team B identification key.

Team B		
Person A		
Person B		
Person C		
Person D		

Table A- 8. Team C identification key.

Team C		
Person A		
Person B		
Person C		
Person D		

CODING TOOL EXAMPLE

Observer:

Analysis Date:

Leadership in Engineering Design
Observation Form

CEDAR

Team Observed:

Observation Date:

Source Video File:

Leadership Behavior Coding		Design Activity Coding		Individual Behavior Coding						Attendance						Time Recordin	
Number	Leadership Function	Design Space	Design Activity	Per. A	Per. B	Per. C	Per. D	Per. E	Per. F	Per. A	Per. B	Per. C	Per. D	Per. E	Per. F	Start Time	End Time

Time Required: ______________

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Template Updated: 1/24/2018

DEFINITIONS OF LEADERSHIP FUNCTIONS

The following section will present the leadership functions that coders are looking for. The leadership functions are presented with definitions and examples. It is important to note that the examples listed are not the only forms of the leadership functions that appear in the recordings.

COMPOSE TEAM

Definition: Selecting individuals that are capable of achieving the goals outlined for the team. This includes selecting team members for their skills, prior experiences, and subject matter knowledge as well as their values, interpersonal skills, and motivations. This function is performed throughout the course of the project, team composition is monitored and adjusted as the team's goals and focus is changed.

If the team is already composed, then the team composition function involves assessing the individuals' skills, knowledge levels, and interpersonal skills and distributing the team members in a manner that will enable the team to achieve its goals and objectives [83].

Examples

Selecting Team Members

- Selecting team members from the pool of individuals qualified to join the team. Things to consider include the individuals' prior experiences, skill level, abilities, and interpersonal skills such as their motivations, values, and their personality.

Establishing Team Roles

- Assigning each team member responsibilities and tasks that the he/she is capable of completing. Ensuring that team members understand how their role fits into the team's structure as a whole.

Monitoring the Team Environment

- Adjusting the composition of the team as the project progresses. Changing the team composition due to outside factors such as being pushed new goals, or internal factors such as poor individual performance or poor group cohesion.

DEFINE MISSION

Definition: Determining and communicating the organization's performance expectations for the team in such a way that they are broken down into tangible, comprehensible pieces. Once the organization's expectations are understood, the team's mission (main goal) can be set.

The "organization" in this definition refers to the group that constructed the team, either the company, faculty members, or customer. The organizations will set a performance expectation and the team then defines its own mission from the organizations larger expectations [83].

Examples

Setting a Team Mission/Goal

- Setting an achievable target for the team to achieve in the available time frame. This mission can be creating physical product being due, a solving a problem, or performing a task. This mission can be assigned from the larger organization or defined by the team itself.

Establishing a Mission Statement

- Creating a mission statement defines the main goal or function of the team. This documents the goal or mission of the team.

ESTABLISH EXPECTATIONS AND GOALS

Definition: Establishing internal performance expectations for team members and setting internal team goals. These goals are more refined and focused for the team functions and individuals on the team, thus making them different from the "Defining Mission" function that focuses on the overarching team goal.

The leader usually works individually or in small groups with team members to establish performance expectations, individual goals, and team operating procedures. These goals and expectations include what each team member is responsible for completing during the project's duration [83].

Examples

Establishing Team Members' Goals

- Each team member's tasks and goals will be identified and documented so that there is a performance target for each member of the team to achieve.

Establishing Team Work Expectations

- Developing expectations for team performance, working expectations, work load expectations, and other performance expectations.

Establishing Meeting Goals

- Setting goals of specific meeting. This sets the team's performance or social goals for the meeting.

STRUCTURE AND PLAN

Definition: Developing a team understanding of how best to coordinate their actions and work together to achieve the goals and expectations that have been established. The leadership function of structure and planning includes determining or assisting in determining how the work will be accomplished (method), who will do which aspects of the work (role clarification), and when the work will be done (time, scheduling, work flow). These behaviors result in an integrated work plan that directs the team's performance, coordinates team efforts, develops task performance strategies, and standardizes team processes [83].

Examples

Establishing Team Roles

- Determining what team members are capable of carrying out the specific tasks laid out in the structure and planning behaviors.

Creating a Plan of Activities

- Laying out the schedule and timeline of the team's work so that the tasks and due dates are clearly documented and understood (examples of charts include gnat charts.

TRAIN AND DEVELOP

Definition: Identifying deficiencies in team capabilities, either in the form of individuals not being able to perform their tasks, or the team not being able to work together to perform their tasks. After the deficiencies are identified, the capabilities need to be further developed so that the team is capable of performing the task at hand.

The capabilities can be enhanced through targeted direct training courses with instruction or demonstration to individual team members or the team as a whole. Alternatively, the training may be on going coaching designed to develop the team over the course of the project. These trainings can be for both task oriented deficiencies or relational oriented efficiencies [83].

Examples

Providing Technical Training

- Identifying that a team member is not proficient in a technical area such as, welding, programming, fabricating, or using productivity tools such as Microsoft office or email. Sending the team member to training courses to improve the technical area that was identified.

Prolonged Coaching

- After identifying a proficiency in the team's, or a team member's, performance, having the team (or team member) work with coaches to develop their skills over time. This type of training could be for technical issues or it could be for relational team issues.

Reference to Educational Tools

- To suggest referencing material on areas an individual could improve it. This is less formal than providing training or coaching, but referring the team (or team member) to educational materials on areas that require improvement is another way of training and developing the team.

Peer Coaching

- Having a team member work with another team member to learn a new skill. Having teammates train each other informally develops the overall skill set of the team.

Sensemaking

Definition: Identifying essential environmental factors/events (internal and external to the team), interpreting these events given the team's performance situation, and communicating this interpretation to the team. This behavior facilitates team understanding of the meaning of external, or inside events, their meaning, and how they impact the performance of the team. Through making sense of specific events for team members, this aspect of team leadership helps the team understand the significance of specific events and enables the team to effectively respond to their impact [83].

Examples

Managing Team Response to Events

- Interprets internal and external events and communicates the impact to the team. This could be as simple as communicating new organizational strategy to the team, or as complex as interpreting conflicting customer needs.

Facilitate Team Understanding of External Events

- Helps fill the gaps and understand how an external event affects the performance of the team.

Facilitate Team Understanding of Internal Events

- Help the team communicate the progress effectively so that all understand the status of the team and where the team is moving towards.

Provide Feedback

Definition: Providing feedback on performance against established goals and milestones, metrics, and expectations, and to the extent the team's performance is not meeting those expectations, adapt and determine more effective ways of functioning.

The feedback can be to the team as a whole or individual team members.

Also, encouraging team members to give each other feedback during the progression of the project [83].

Note that feedback can also be technical in nature. If a teammate is performing a task and another teammate provides technical feedback that alters the teammates task, then this is also coded as providing feedback.

Examples

Formal Performance Review

- A discussion regarding a team member's performance and task completion over a period of time of the project. Performance reviews can occur on a routine basis or by the request of the team, team member, or the external organization.

Peer Evaluations

- Peer evaluations provide all the team members feedback from their peers (teammates). This can be done anonymously or open, however, the point is to gain an understanding of how the team views its current performance and where improvements can be made.

Providing Technical Feedback

- Providing critical or positive feedback regarding a design decision or a technical concept. This can be done in a formal or an informal matter and can be done internal or external to the team.

Monitor and Guide Team Tasks

Definition: As team is actively involved in work, the team's progress and performance must be monitored to ensure the team is on target for reaching their goals. This leadership functions deals with examining the team's processes, performance, and the external team context. This includes evaluating the team's progress towards task completion with regards to the resources available to the team, the external environment, and individual team member roles [83].

Examples

Evaluating Team Performance

- Tracking the team's completion of goals and work steps as it works towards achieving a larger team goal or the team mission.

Surveys Team Members

- Asks the team members where they're at with their tasks to better understand the current state of the team.

Identify Need for External Resources

- Monitoring the teams processes and determine if external resources are required to complete the tasks in a more efficient way.

Manage Team Boundaries

Definition: Managing the relationships between the team and the external environment (other teams, the larger organization, customers, and other influences on the team). Managing team boundaries also includes buffering the team from the impacts of external events and making sure that the team is capable of reacting to a changing external environment.

The team's boundary must be tight so that the team roles and relationships are understood, a sense of teamwork is established, and the team can be recognized by other teams and organizations. However, the team's boundary must also be loose so that it can adapt and react to external events and changes in scenario. This leadership function involves managing the state of the team boundary throughout the course of the project [83].

Examples

Establishing a Team Boundary

- Creating a standard process for team members to interact with the external influences. This process will dictate how information flows to, from, and through the team.

Managing the Team's Relationships

- Establishing relationships with other teams or the external organization is a key part of managing the team's boundaries. Teams often times have to work with other teams and interact with the larger organization they are a part of. To be effective, teams need to effectively manage their relationships with other entities.

Challenging the Team

Definition: Challenging the team with respect to their performance levels, processes, standards (rules & regulations), and attitudes. The goals of challenging a team are to improve their performance output, working relationships, or strengthen the identity of the team. All of these goals aim to make the team more effective.

Challenging the status quo and making sure that team mates do not become stagnant increases the team's focus toward their goals and relationships [83].

Examples

Raising Performance Goals

- Increasing the performance goals of a team as the team progresses through the action phase of a project makes the team come together and refocus to achieve the new, higher, performance goals. This challenge could be brought on by external events (customer demand, organizational push, or other events external to the team), or by internal events (team is stagnant, performance is low, or team is now working hard enough).

Challenge Teammates to Get to Know their Peers

- Challenging the team to get to know each other might be necessary if the team is newly minted and has not had the time to get to know each other through work. Additionally, if a team is not functioning well as a project progresses, challenging the team to get to know each out will provide an opportunity for the team's performance to improve.

Perform Team Task

Definition: Taking a more active role in the team tasks. Performing work required for the team activity or project. This can be done individually or participating with other teammates [83].

This is aimed at external leaders who are not involved in the day to day activity, but can be considered for internal leaders responsible for portions of team projects or internal leaders assisting other members with their tasks [83].

Examples

Working on a Team Task

- If an internal team leader is responsible for completing a portion of the team project, the act of working on the task is considered performing a team task.

Solve Problems

Definition: Diagnose and solve any problems that keeps the team from realizing and achieving its potential. This is a crucial function of team leadership as team leaders must be able to identify problems that are holding their teams back and then provide effective and timely solutions. Any problems the team faces can be addressed by the leader (team relations, task oriented, or external influences) [83].

Examples

Internal Conflict Resolution

- Solving problems amongst team members. These problems may be relational or related to team tasks.

Logistical Problems

- Identifying potential logistical problems between the team and the external environment. Making sure the expectations for the team are realistic and providing logical solutions to the logistic challenges.

Provide Resources

Definition: Acquiring financial, informational, material, and personnel resources for the team to use to complete their tasks and achieve the team mission. First, the resources must be secured before they can be provided to the team. The resources acquired can be for task oriented situations or to support and motivate the team or improve team relations [83].

Examples

Increasing Team Budget

- Increasing the team's budget when necessary. This could involve raising funds for the project as a team, or going to the organization and requesting an increase in the team's budget.

Providing Personnel

- Increasing the team size when the amount of work is greater than the working capacity of the team.

Outsourcing Work

- Identifying work that can be done external of the team and reducing the work load by providing a service that can accomplish any non-essential work.

Encourage Team Self-Management

Definition: Encouraging the team to manage itself and perform its own leadership functions. This involves encouraging (and helping) the team solve task and teamwork related problems on their own. Additionally, encouraging teams to establish their own resources and relationships with external partners (organizational, customers, etc…) [83].

Examples

Having the Team Solve its Own Problems

- Standing back and letting team members resolve the task and relational problems within the team.

Letting the Team Establish Goals

- Having the team set the performance goals and timeline for their execution.

Encouraging Team Leadership

- Encouraging the team to perform the leadership functions on their own.

Support Social Climate

Definition: Supporting the team's social climate involves dealing with interpersonal issues that may hinder the team's performance. This also includes finding ways to motivate the team and make their work feel relevant to keep the team members involved. This function focuses and making sure the team is functioning as a unit and that there are not team issues hindering performance [83].

Examples

Motivating Team Members

- Finding ways to make sure that the team is motivated to accomplish the tasks and goals besides the sole fact that the due data is approaching.

Resolving Any Social Conflicts

- Immediately solving social conflicts in a way that reduces an impact to the team's performance and allows for all team members to resume normal work.

Ensuring Equal Treatment

- Making sure that all team members are treated equally regardless of their team position or any social beliefs.

Consideration

Definition: Showing concern and respect for individual team members. Being friendly and approachable so that all team members feel comfortable discussing any team or project issues. It is important to treat all group members the same way and do not hold any member above the team or treat any member worse than the others [173].

Examples

Treat all Team Members the Same

- Making sure that the team members are all treated equally when they perform well or poorly.

Being Friendly and Open to Discussion

- Brining a snack or coffee to teammates to keep the motivation high or to build trust to create an open dialog.

Empowerment

Definition: The act of strengthening an individual's beliefs in his or her sense of effectiveness. This is the process of building confidence in team members by increasing their self-confidence [174].

Examples

Allowing Team Members the Chance to Try New Things

- Giving team members the opportunity to test their skills through new tasks lets them know that they have the confidence of their leader, thus building their self-confidence.

Encouraging Words

- Positively reinforcing the team through verbal feedback, written feedback, and other forms of positive feedback.

Supportive in Stressful Situations

- Letting team members know that they have the support and confidence during tough conditions (task or personal related).

Engineering Design Space Definitions

The design space needs to be coded to track what aspect of the design space the team is working on when a leadership function is observed. The design space is broken into three categories, Problem Space, Solution Space and Project Space.

Problem Space

Problem space is defined as working on understanding the problem, the users, or the use cases. This includes developing new requirements, questioning the customer regarding their needs, and developing a problem statement.

Solution Space

The solution space contains any work revolving around the design of potential solutions. The design of potential solutions includes concept development, concept evaluation, identification of functions, embodiment design, detailed design, fabrication, and testing. Any stage of prototyping is also included in the solution space.

Project Space

The project space is defined as any situation where the team is not dealing directly with the problem or the solution. Examples include, but are not limited to, planning team meeting/work sessions, identifying team goals for the semester, assigning responsibilities to team members, evaluating team performance, and many others.

Engineering Design Activities Definitions

<u>Synthesis</u>

The creation of new material that is relevant to the problem, solution, or project. The creating a requirement, function structure, or physically constructing a prototype is considered synthesizing new design information or material [5,8,175]. Note, there are other types of design analyses available to design teams and that this is an incomplete list.

<u>Analysis</u>

Analysis of design problem, solution, and project deals with studying the current design information and materials available to the design team. Some examples of analysis include a Finite Element Analysis (FEA) of a structural component of their design, a Failure Modes Effects Analysis (FMEA) of the design solution, or a cost analysis of the design solution [5,8,175]. Note, there are other types of design analyses available to design teams and that this is an incomplete list.

<u>Decision Making</u>

Decision making activities include the review of analysis and the current design information to change the direction of the design team, identify new tasks that need to be completed, move forward with one concept over others. Decision making activities can include one team member or multiple [5,8,175]. The list of decision making activities is not complete, however, these present some of the activities that coders may observe.

Transformation

Transformation activities are the process of taking design information in one representational state and transforming it into another. Examples of this include, but are not limited to, transforming a sketch of a solution into a 3D CAD model and taking a list of handwritten requirements and creating a complete requirement sheet [175].

Communication

Communication includes any communication of design information or material internal or external to the design team. Examples of communication can include emailing, updating face to face, calling, texting, etc. design information to customers, advisers, teammates, vendors, or other entities associated with the project. Communication involves all domains of the design space. Design team members can communicate problem, solution, and project information internal and external to the team. Communication also includes calling for new goals, structure, or new design information. For example, identifying that a team needs to create a function structure is communicating a new goal, not synthesizing new design material.