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Engineering Leadership Across Disciplines: A Systematic Literature Review*

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Accrediting bodies, the National Academy of Engineering, and industry representatives have indicated that future engineers must be able to both understand and apply leadership in solving engineering problems. In response, the concept of engineering leadership has grown dramatically over the past decade. This paper presents a systematic literature review of the field of engineering leadership, describing how engineering leadership is being understood, applied in industry, and assessed across a variety of engineering disciplines. The literature suggests that some fields, such as industrial engineering and civil engineering, have more quickly pushed into education research in engineering leadership. Definitions of engineering leadership have not converged to a consensus, but common attributes, skills and competencies have emerged across disciplines. The literature highlighted a variety of different courses, programs, and training that worked to develop leadership skills within engineers. However, across fields, the literature suggests a deficiency in validating these proposed solutions through objective assessment.

Keywords: engineering leadership; interpersonal; competency models; engineering education; early-career engineers

1. Introduction

The NAE's 2004 call for reform in engineering education, the "Engineer of 2020", included the need for future engineers to both understand and apply leadership in solving engineering problems [1]. ABET has answered this call with criteria for accreditation that highlights teaming and leadership to include creating collaborative and inclusive environments, establishing goals, planning tasks, meeting objectives and recognizing ethical and professional responsibilities [2]. These changes are showing up in accrediting bodies in not just the US, but Canada, Australia, and throughout Europe [3–5]. Engineering educators planning for review cycles are tasked with meeting these new criteria.

Engineering educators, unable to increase credit hours to accommodate non-technical aspects of engineering, are challenged to find ways to effectively incorporate these professional skills into curriculum. The nature of leadership as a phenomenon and its long history of scrutiny and scientific study has resulted in a wealth of theoretical approaches that are difficult to condense for effective application in various contexts. Attempts to summarize this information point to trends in contextually specific leadership research [6]. Engineering education research has seen growth in

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leadership specific to engineering. The ASEE professional society for engineering education noticed this trend and developed an Engineering Leadership Development Division (LEAD) in 2015, which now boasts over 1,000 members. Prior to that, the American Society for Civil Engineering (ASCE) published a Leadership and Management in Engineering Journal, and although short lived, produced 13 volumes of peer-reviewed articles towards the subject. Submissions in engineering education journals like JEE, IJEE and leadership specific journals have produced engineering leadership focused research. Rottman, Reeve, Sacks, & Klassen reviewed and categorized engineering leadership research into five categories focused on undergraduate engineering education: Calls for engineering leadership, engineering leadership program descriptions, competency-based depictions of effective engineering leaders, empirical studies of engineering leadership in industry, and conceptual examinations of leadership from an engineering perspective [7]. These articles depict varying viewpoints, application, and research for engineering leadership at the undergraduate level, providing a general perspective of the phenomenon for engineering educators to consider.

While the push from the NAE in 2004 set in motion these general trends, discipline specific application of engineering leadership is an area that is yet to be explored. The purpose of this systematic literature review is to describe and synthesize the state of knowledge and practice related to engineering leadership within a set of engineering disciplines. In order to address the state of knowledge, this study seeks to disseminate how engineering leadership is being understood, applied in industry, and assessed in engineering disciplines. The aim is to synthesize this work as engineering educators not only embark on accreditation cycle requirements but seek to meet workforce demands for the engineer of the future. The research questions associated with this purpose include: (1) What are definitions or descriptions of leadership attributes, competencies, and skills (2) what assessments are being used within each discipline, and (3) what types of education or training methods are being implemented.

2. Methods

As a relatively young focus of research, a systematic literature review for engineering leadership falls into a category defined by Borrego, Foster, and Froyd as describing a state or knowledge [8]. This strategy was chosen for its ability to provide a picture of the current state of engineering leadership research as well as support growth for methodologies and research initiatives [8]. Further, this systematic literature review category supports the ASEE LEAD division's initiatives. The ASEE LEAD division set forth strategic goals focused on assisting administration and faculty in understanding the value of engineering leadership education, how to create and fund programs, develop effective curriculum, and describe the diverse needs of engineering leadership across industries and disciplines. As such, the authors worked with LEAD division members with expertise across different disciplines to conduct the study. The method and approach to this systematic literature review was highly informed by Borrego, Foster, and Froyd, and employs a high level of collaboration across engineering leadership educational institutions. The team of researchers consisted of eight engineering leadership scholars who are involved in engineering leadership curriculum or research. The team together discussed the disciplines to be considered for the study.

2.1 Phase 1 – Database Searching

Search criteria. The initial search outlined for collaborators required an approach that included discipline specific publications but also engineering education resources. Authors were encouraged to also search using Engineering Village and Google Scholar. Our initial goal was to identify discipline specific articles found in discipline specific publications but to also expand to general engineering education and industry research. Search terms initially focused on [discipline + engineering and leadership] and limited to the timeframe of 1999–2019. Researchers narrowed results by selecting peer reviewed literature and a leadership focus in abstracts. Results returned from the initial review were scrutinized based on their relevancy to the specific discipline. Papers were retained if they were specific to the engineering discipline searched and included either a post-secondary or professional focus. Additionally, papers that were purely editorial in nature were not retained. All authors were required to record if inclusion criteria were met in a shared document. The search term, article title, publication name, primary engineering field of publication, and primary field of participants or focus of the study were recorded. Once these were documented, authors began reviewing full texts of the documents. The most common reasons for eliminating a document included a lack of focus on the specific engineering discipline and a lack of focus on leadership for that specific discipline. Fig. 1 describes the full process of paper review for each individual author. Table 1 provides the numerical results of the search and screening process for each discipline throughout the systematic review process.

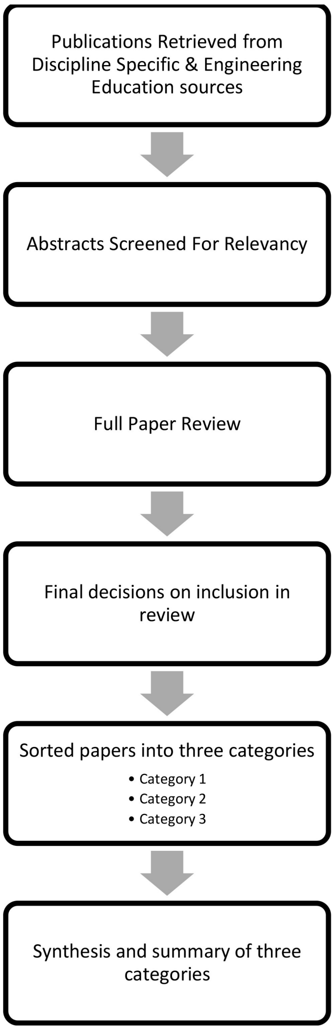

Fig. 1. Systematic Review Process.

2.2 Phase 2 – Sorting Papers

Research Question Sorting. Upon determination of appropriate articles for full review, the authors proceeded to review the full texts of the list of identified papers. After review, the authors sorted the papers into the appropriate research question: (1) How are the various disciplines defining or describing leadership attributes, competencies, and skills in engineering leadership, (2) what assessments are being used within each discipline, and (3) what types of education or training methods are being implemented. As problems arose to determine which category the article fell into, the authors would review and discuss to determine appropriate fit and recording of the article's focus. After each article was placed into one of the three categories, the authors reviewed accepted articles in depth and prepared a summary within each of the three research questions listed above that included key information for each category. For category one, researchers identified papers that worked to define leadership attributes and noted when articles empirically identified key engineering leadership competencies or anecdotally identified important competencies for leadership in the specific engineering discipline. Key engineering leadership competencies were determined based on an in-publication study that included a literature review and focus group with industry representatives. The study identified 18 competencies which were used as the framework to identify the competencies in category one of this study. Researchers tallied the competencies noted through analysis of articles in category one. Category two required researchers to make note of validated research instruments used in identified studies. For category three, researchers compiled the type of education or training method used as well as the demographic, undergraduate, graduate, or professional.

The three research questions served as the categories by which the articles were sorted. These three

Table 1. Engineering Leadership Systematic Review Categorization Overview

Discipline	Total Publications Retrieved	Abstracts Reviewed	Full-text review	Included in synthesis	No. Category 1	No. Category 2	No. Category 3
Aerospace	2	2	2	1	1	0	0
Biological	754	16	3	0	0	0	0
Biomedical	805	10	4	3	1	1	1
Chemical Engineering	357	41	10	8	3	1	4
Civil/Construction Engineering	984	64	32	11	1	3	7
Computer Engineering, Computer Science, Electrical Engineering	96	31	16	9	7	2	1
Industrial	136	38	13	12	8	0	4
Mechanical	1296	93	51	25	12	8	20
Nuclear	0	0	0	0	0	0	0
Totals	4430	295	131	69	29	16	33

categories of research questions were determined based on a pilot study conducted by the authors. The pilot study, conducted in 2018, analyzed the engineering leadership literature for the civil engineering discipline. The three themes emerging from that research included definitions or descriptions of engineering leadership, assessment of leadership attributes, and descriptions of leadership education or training methods [9]. This initial pilot study assisted in providing the structure and methodological testing for the current study.

2.3 Validity, Reliability, and Limitations

Validity and Reliability. Since multiple authors were to review disciplinary literature for this study, reliability was an important consideration. Authors worked collaboratively to define the search criteria, outlined in 2.1, and expanded from the 2018 pilot study [9]. The team members purposively chose indexes and publication outlets relevant to their individual disciplines. These were then discussed and agreed upon amongst the research team. The team members' results to include the specific search criteria and database were recorded to support replication and ensure consistency across searches. As recommended by Borrego, Foster, and Froyd specific pieces of literature in which this study's authors had uncertainty as to relevance or categorization were discussed amongst authors for consistency [8]. While team members across disciplines did not discuss uncertainty, the two lead authors provided the support for discussions with the discipline specific team member. This supported interpretive both and thematic inquiry as team members moved through the systematic review process. Snowball sampling, though often recommended in systematic reviews, was intentionally not performed during this study, as it had the potential to introduce additional biases and could lead to unintentional violations of the inclusion criteria. Instead, purposive sampling supported validity in that searches were centered on the specific discipline and leadership.

Limitations and Biases. Though authors attempted to remove as many potential opportunities for bias as was feasible, a variety of potential biases still exist within this systematic review.

Inclusion criteria and search biases. This systematic review focused on publications written in English, excluding a significant portion of the literature in other languages. Leadership and other professional skills vary amongst cultures and demographic groups, and this research likely has a bias towards the engineering leadership approaches, definitions, and attitudes of those in predominately English speaking countries. Additionally, though this research attempts to gain a holistic view, publications that are not indexed through common databases may have been overlooked.

The systematic review also focused on specific disciplines determined by the research team but may still exclude a variety of relevant engineering disciplines. Additionally, the systematic review excludes publications that are not housed within an engineering education context. This exclusion includes a large quantity of literature in the business and management fields that focuses primarily on general leadership rather than "engineering leadership" as defined in this study.

Publication bias. There is also a significant risk of publication bias with research question 3, which seeks to explore what types of education or training methods are being implemented. It is less likely that authors will submit, or editorial boards will accept, publications in which the studied education and training methods are ineffective or unproven. Though this does provide the intended audience with more exposure to those methods that have evidence of effectiveness, it does exclude potentially useful data regarding which practices are less effective or are deemed less valuable uses of resources.

3. Results

3.1 Aerospace Engineering

Aerospace Engineering reported two articles emerging from the data search, with only one aligning with the goals of this paper specific to category one. The research focused on business competencies essential for success for new aerospace graduates based on interviews with 200 aerospace engineers in the workforce, ranging in experience from interns to 35+ years of experience [11]. Through qualitative analysis, 15 competencies emerged related to business acumen. Business management, communications, team work and working in teams, and business ethics were competencies listed related to leadership. While the article did not specifically note leadership, it discussed the importance of specific skills such as written and verbal communication for upward mobility and enhanced management positions.

3.2 Biological Engineering

Biological Engineering reported three articles emerging from the data search, with none aligning with the goals of this paper.

3.3 Biomedical Engineering

Category 1: Definitions or descriptions of leadership attributes, competencies, and skills

Hendricks, Yashuhara, and Taylor described how in a series of two courses, students were introduced to leadership competencies through The Student

Leadership Competencies Guidebook: Designing Intentional Leadership Learning and Development by Corey Seemiller in 2014 [12]. These competencies include ethics, analysis, conflict negotiation, communication, providing/receiving feedback, problem solving, decision making, and personal contributions to effectiveness of group. Throughout the courses, students spent time reflecting on their work and how it relates to the leadership competencies. The authors implemented self-assessments to determine the perceived effectiveness of the use of self-reflections as a pedagogical approach to leadership competency development. Descriptive statistics suggest positive experiences in reflective experiences as a means to develop leadership competencies and understanding of leadership in general and within the biological leadership perspective. also suggest that the use of reflections were a good pedagogical approach that worked to develop leadership competencies (based on a self-assessment) and better understand what leadership means [12].

Category 2: Assessment of leadership attributes

A 2016 study focused on leadership identity and motivation to lead through leadership interventions in a biomedical engineering class and was the only study focused on assessment. The study aimed to assess if leadership interventions resulted in a growth in leadership identity and motivation to lead peers [13]. The study assessed leadership attributes through the leader identity and affective-identity motivation to lead of a control and intervention section of the same course. Students in the intervention section were provided with leadership training through the Clifton StrengthsFinder assessment, training workshops and assigned leader roles. Students were assessed and given feedback on interpersonal and team dynamics using the CATME system. Findings suggested that intentional leadership-oriented training and practice opportunities embedded within bioengineering curriculum can support leadership identity development and team collaboration.

Category 3: Description of leadership education or training methods

With regard to leadership education in biomedical engineering, only one article emerged. The paper described a capstone course in which students apply to become "team lead" nine months in advance of the semester long course. The students participated in two one-credit team leader courses in advance of leading a capstone course. The first course focused on clinical observation where students learn as a team with medical school faculty. In the second course they learn about team formation, organization and operation, and project management. Following these courses students who participated in the leadership training then select teams and are responsible for teaching others through leading the capstone course [14]. This article described an elaborate leadership training to support capstone course management and outcomes, using a student led approach.

3.4 Chemical Engineering

Category 1: Definitions or descriptions of leadership attributes, competencies, and skills

Chemical engineering literature returned three articles related to the identification of leadership attributes. The papers identified in this category focused on understanding perspectives of skills needed in chemical engineering work. The first, a 2005 study, focused on graduate' perceptions of being prepared for work in industry [15]. The study differentiated between the science of engineering and the practice of engineering. Semi-structured interviews were conducted with chemical engineering students. The second [16] surveyed supervisors' perceptions of competencies of recent graduates. The third [17] surveyed both current students and alumni to rank order employability skills for chemical engineering graduates. This study used a list of skills assessed and supported by the World Chemical Engineering Council. These studies similarly noted that leadership attributes were lacking in recent graduates and should be incorporated into curriculum. Specific skills noted in these study that aligns with leadership included communication, teamwork, and interpersonal competencies. With a 12-year difference in research, the articles noted that leadership curriculum in engineering education is lacking and that comprehensive curriculum that meets the needs of a global workforce is still a need within educational offerings.

Category 2: Assessment of leadership attributes

One empirical research study compared the leadership abilities of men and women in undergraduate chemical engineering teams. This study hypothesized differences in leadership styles between men and women. Findings from this study suggested that women lead with more relational styles and men tended to lead with more goal-oriented styles. Ratings of leadership were ranked on a Likert scale consisting of measures of management skills, moderation skills, motivational skills, and empathy skills. Team members rated leader performance in these skills twice during the course of the project. Findings suggested that women's leadership styles support and maintain social exchanges resulting in higher cohesiveness in teams initially [18]. Results of evaluation towards the end of the project evaluate leadership styles effectiveness of men and women similarly. The researchers suggest that stereotypical tendencies of women leaders may be beneficial for engineering teams and organizational context with high networking, collaboration, or history of conflict and communication issues [18].

Category 3: Description of leadership education or training methods

A diverse area of research emerged related to descriptions of leadership education training methods relevant to chemical engineering curriculum. The studies differed in approaches ranging from project-based learning to personal development and workshops to full program integration. All the descriptors of leadership curriculum in engineering education centered on competency gaps identified by industry. As noted in the category one, communication remains a skill-gap in engineering education. Each of the programs described an element of communication development. However, the two studies that focused on undergraduate curriculum focused on interpersonal elements of communication [19, 20], while the two graduate studies focused on presentation style communication (written & verbal) [21, 22]. Noting the difficulties of incorporating additional required content into undergraduate curriculum, the undergraduate studies suggested two approaches. One educational institution implemented workshop style approaches which provided experiential learning focused on personal leadership, team leadership, and societal leadership. The workshop was developed with social change leadership in mind [19]. The second undergraduate program outlined a competency-based structure for engineering curriculum that integrates leadership practice in ever-increasing intensity throughout a five-year chemical engineering curriculum. The curriculum would integrate workshop style approaches throughout the program appropriate for the level of project leadership required during the course of the year [20]. Facilitative leadership and social learning theory formed the basis for the leadership development in the curriculum. Experiential learning through yearly design projects formed the basis for the technical component of the competency-based curriculum structure. For the graduate programs, both institutions recognized the need for employability skill development in graduate education. Specifically, one study evaluated the destinations of masters and PhD students at six different institutions, finding that a majority went outside of traditional academic and research roles [22]. The studies suggested added curricular or co-curricular structures that included leadership and management knowledge and skill development and suggested communication (verbal and written) that is non-research based be incorporated into chemical engineering graduate programs.

3.5 Civil/Construction Engineering

The Civil and Construction Engineering literature is expansive due to the connection with project management and construction management. For the purposes of this paper, the criteria for review for this discipline narrowed results by focusing on articles that specifically targeted civil engineers, construction engineers, or civil engineering companies within the sample or focus. The robust research in project management and construction deserves a singular focus and is outside the scope of this paper. Through the systematic literature review search, a comprehensive literature review on leadership within the construction industry was found [23]. Please refer to this article for previous research in the construction management discipline.

Category 1: Definitions or descriptions of leadership attributes, competencies, and skills

Civil and Construction Engineering literature reviewed returned one article related to category one. The article focused on growth in civil engineering projects in the developing world and the need for effective leadership of cross-cultural construction engineering teams [24]. Using qualitative methods, the researchers conducted focus groups with project engineers, directors, and managers of projects in the Kenyan and UK construction industries to explore effective leadership attributes for cross-cultural teams. The data analysis resulted in a framework suggesting that effective multicultural performance depends on leadership that can provide a (1) clear project purpose, objectives, values, roles, and processes, (2) cultural understanding through leadership, and (3) cross-cultural action. Cross cultural action included adjusting leadership styles for cultural norms, effective team development and selection, cross-cultural communication, collectivism, management, and the ability to deal with cross-cultural uncertainty. The research noted differences in leadership style preferences across cultures, the need for training, and the necessity of acknowledging and valuing cross-cultural complexities within construction engineering teams [24]. The authors suggest implementation of the eight elements of cross-cultural action to lead multicultural construction engineering teams toward high performance.

Category 2: Assessment of leadership attributes

Three studies emerged within the assessment category of civil and construction engineering literature. Two of the studies assessed leadership behaviors through the application of traditional leadership theory. Leader-member exchange (LMX) theory framed the analysis of Korean civil engineering leaders' relationships with subordinates and subsequent differences in perceptions of soliciting feedback. Findings suggested that in perceived positive superior/subordinate relationships, superiors think they use direct feedback seeking strategies with subordinates. Subordinates identified feedback-seeking behaviors of leaders to be more passive and indirect [25]. Results from subordinates indicated positive reactions to leaders who implemented direct cue monitoring to internalize feedback from subordinates. Direct cue monitoring is characterized by "paying attention to informal and unsolicited feedback" from subordinates [25], pg. 160. Ultimately, leaders understanding the differences in comfort level of employees in giving feedback to a superior is important for building relationships. Authors suggest that civil engineering leaders and workers should work to better understand differences in feedback-seeking behaviors to improve superior/subordinate relationships. The second study applied contingency theory, specifically utilizing the Producer, Administrator, Entrepreneur/Developer, and Integrator (PAEI) model to assess effective leadership behaviors on key drivers of a construction project. The researchers hypothesized positive impacts of each of the PAEI styles on time, cost, and quality of civil engineering projects. Surveys were sent to project engineers in the civil engineering sector of the Swedish Transportation Administration to examine the effects of different PAEI leadership styles on project performance [26]. Findings suggested that leadership styles implemented in various project situations influence the successful project performance. The authors suggest that leadership style be included as a critical success factor in literature for civil and construction managers [26].

The final study in this category focused on the implementation of performance management models in large construction engineering organizations with the aim of identifying motivations for implementation and the success of those implementation efforts [27]. The researcher used a case study approach to interview and observe implementation methods of eight civil engineering and construction engineering organizations, of which four were reported in the study. The firms implemented EFQM Excellent Model and the case study analysis explored the planning, deployment, assessment, and review of the effort. Analysis revealed challenges within each firm's implementation and the need for the civil/construction engineering industry to adopt best practices for performance management models.

Category 3: Description of leadership education or training methods

Seven articles described education or training methods for civil engineer or construction engineers. Two articles focused on project-based learning in the form of service to support the development of leadership in civil engineering students [28, 29]. Padmanabhun et al., described leadership topics embedded throughout the course in the form of guest speakers or leadership topic discussions while Plumblee et al., describes leadership development through selected project managers meeting deliverables and project goals [28, 29]. One article outlined the need for a leadership training program to nurture future civil engineering leadership [30]. Developers of the training program identified key leadership characteristics through discussion with engineering leaders and managers and developed the program centered on the identified key attributes. The article describes the evolution of the program, lessons learned, and anecdotal evidence for its success. Two articles outlined methods for embedding leadership into civil engineering course work. One described the use of the engineering design process as a way to prepare students for engineering leadership challenges [31]. The process begins with a needs assessment of the leadership challenge and concludes with an implementation plan. The paper suggests incorporating leadership development through the implementation of a design project within civil engineering courses. Grigg's 2011 work suggests the use of case studies in civil engineering courses to build knowledge of the leadership and management challenges within complex technical problems. The author suggests that technical methods alone are not enough to combat leadership and management issues related to the complexity of water supply, water quality, water for energy, and other water management issues [32]. Analyzing cases by asking both the technical challenges and the leadership challenges provide knowledge of the holistic complexities within civil engineering challenges. The final two articles discuss graduate program curriculum and the need or implementation of leadership development activities. Levitt summarizes the success of six decades of research in the Construction Engineering and Management graduate degree [33]. The author describes progress within sets of decades and concludes with the need to have more of an integrated and holistic approach to construction engineering management research for the future. Ellis & Peterson describe an adapted MS program which incorporated learning objectives and assessment related to leading civil engineering teams [34]. Assessments included 360-degree feedback for students leading teams throughout the semester and positive evaluations towards course learning objectives. The article describes the restructuring of the graduate program, curriculum goals and objectives, individual course outcomes and evaluations.

3.6 Computer Science, Computer Engineering and Electrical Engineering

Category 1: Definitions or descriptions of leadership attributes, competencies, and skills
Electrical and computer engineering literature addresses a wide range of diverse leadership attributes, competencies, and skills that may be loosely grouped into two categories: interpersonal skills, such as mentoring, communication, relationship management, and coordination; and personal expertise, such as technical competence, problem solving, and business acumen. More studies focused on interpersonal skills [35–40] than they did personal expertise [41]. Most of the literature related to definitions or descriptions of leadership attributes, competencies and skills, suggesting perhaps that the research around leadership in electrical engineering and computer science is still in a relatively nascent stage, where researchers are more concerned with understanding, defining and describing leadership than they are with assessing or developing it.

Category 2: Assessment of leadership attributes
Two studies – both in the computer science field – named specific leadership assessment tools [40], [42]. The assessments cited – the Fiedler Least-Preferred-Coworker questionnaire and the Multifactor Leadership Questionnaire, respectively – were administered to subordinates or coworkers of the subjects (the leaders) of the studies in order to assess leadership styles and abilities. One study describes how the Fiedler method was used to assess teams' perceptions of female leaders in software projects [40]. The other cites the use of the Multifactor Leadership Questionnaire to research the relationship between subordinates' level of burnout and how they perceive the leadership style of their direct supervisor [42]. Neither study assessed students' leadership attributes or described leadership assessment in academic settings as leaders were assessed in professional settings.

Category 3: Description of leadership education or training methods
One study described leadership education or training methods [38]. Written by student authors for an IEEE publication, the study analyzed the leadership development benefits of honors and professional organizations. The authors present a number of leadership development opportunities observed in such organizations, which were related to project-based learning or experience focused. None of the studies reviewed provided an in-depth description of leadership education or training methods in academic curriculum.

3.7 Industrial Engineering

Category 1: Definitions or descriptions of leadership attributes, competencies, and skills
Engineering leadership research within the industrial engineering (IE) field has broadly framed the concept in three different ways: leadership connection with IE concepts; leadership in terms of ethics; and leadership styles. Leadership connection with IE concepts includes the following: comparing progression through the stages of six sigma quality management with leadership development [43]; comparing systems thinking and technical skill with promotion success [44]; and using total quality principles to develop leadership [45]. Leadership in terms of ethics oriented leadership attributes in terms of how they serve society's needs, explicitly addressing concepts such as wisdom, courage, service, humility, and transcendence [46–48]. Leadership styles were discussed in terms of increasing complexity and engagement [49] of course – but also in terms of appropriateness (e.g., short-term, simple, fast-paced projects may actually function more effectively using traditional, top-down approaches [50–53].

Category 2: Assessment of leadership attributes
While very little of the existing literature on industrial engineering leadership explicitly addresses specific leadership assessments, the idea may be inferred by a careful review of how leadership is discussed [43, 51]. For example, during Dvir and Berson's discussion of the Full-range leadership model, they specifically discuss differences in motivation, as people move from calculative-rational to emotional-expressive (transactional and transformational paradigms, respectively) [51]. In this case, these descriptive terms may be used to assess the current developmental level of individuals, as organizations strategically cultivate development of their employees. The exception to this loose coupling between leadership traits and assessment is Smith's work on servant leadership, where a specific questionnaire is presented to measure the level of one's servant leadership, in terms of building relationships, enabling others' success, etc. [48]. The results of this literature review indicate that very little work has been done to explicitly assess leadership characteristics within the industrial engineering field, even if much may be inferred about leadership quality, simply by viewing ideal leadership characteristics as a datum against which one may be compared.

Category 3: Description of leadership education or training methods

Leadership training or development research emergent in this study broadly discussed methods or practices that had demonstrated effectiveness in a particular proven leadership program. Traditionally co-curricular activities such as teamwork challenges, seminars, and labs form the core programmatic approaches to leadership development [46–48, 54], even when developed within the context of an engineering curriculum [43, 55]. In addition, workplace-based discussion of leadership development included employee development approaches and techniques [45, 51]. The literature also emphasized conditionality of specific approaches (e.g., hands-on labs require effective facilitation; or leadership may be cognitively taught if it is accompanied by active practice). Of course, additional information regarding training may be inferred from literature discussion of what makes a good leader, even if the process is not explicit in the literature.

3.8 Mechanical Engineering

Category 1: Definitions or descriptions of leadership attributes, competencies, and skills

An examination of the attributes, competencies and skills associated with leadership in the mechanical engineering context provided a wide assortment. Twelve papers were identified as category one and addressed these topics [56–66]. Overall, the salient concepts that arose from the analyses were communication and inspiration. The next most prevalent concept was Mentoring/Coach/Counseling. The third most prevalent concepts were Business Acumen, Relationship Management, and Vision. These results are not surprising given that, as Northouse [67] describes, leadership is an "influence process" and effective communication is often necessary for a person to influence a group. The prevalence of management related competencies are considering the very close relationship between leadership and management often described in the literature [57]. Finally, given the relationship between leadership and goal accomplishment, the prevalence of Vision as a skill is unsurprising. To influence a group toward common goals, explaining a clear vision is an integral to developing a common understanding of a group's goals.

Category 2: Assessment of leadership attribute

The mechanical engineering leadership literature overwhelmingly assesses leadership in an academic setting, and most typically for fourth-year students, but with a broad assortment of instruments. These instruments ranged from internally developed surveys [68] to a modified version of the well-established Multifactor Leadership Questionnaire [69]. Given the breadth of established industrial-organizational literature highlighting established leadership measurement instruments, these findings are somewhat concerning. Given the general consistency between the leadership competencies described above with common definitions of leadership, there may be merit in leveraging and validating existing instruments as a starting point for leadership assessment within the profession before developing novel measurement techniques.

Category 3: Description of leadership education or training methods

Overall, the mechanical engineering leadership literature indicates that leadership is a concept most often relegated to the undergraduate, fourth-year, 'capstone' experience. 14 papers identified undergraduate students as the target for leadership development [58, 59, 62, 63, 66, 69–77] and 13 papers identified the classroom as the location for leadership development [58, 59, 63, 66, 69–77]. These articles overwhelmingly focused on project-based learning within a classroom setting. Given the team-base nature of many mechanical engineering capstone design programs [78] the focus on leadership in this context may be appropriate. The dearth of professional (post-undergraduate) leadership literature within the mechanical engineering context is concerning given the aspirations set forth in the Engineer of 2020 [1]. Overall, the concept of leadership development seems relegated to on-the-job training, and the "learning by doing". To develop leaders within mechanical engineering professional settings, there is much room to grow.

4. Discussion

Accrediting bodies such as ABET built upon early workforce research to influence curricular innovations to meet workforce needs for engineering graduates. This research study, focused on literature emerging during the initial calls for reform through present day, found that earlier studies empirically identified deficits in new graduate skills and are identified in category one of this study. These studies continued to support the call for reform. Studies evolved to focus on descriptions, category three, which focused on describing course, programs, and training that worked to develop leadership skills within engineers. The second category, assessments, is the least populated category. The narrative is predictable in that the need was identified by research, and that academics and practitioners have developed and implemented a wide range of ideas in an attempt to address the need. However, the literature suggests a deficiency in validating these proposed solutions through empirical assessment. This deficit in assessment shows a clear need for evolvement of the discipline to focus on assessing leadership development curriculum, programs, and training initiatives. There are also disciplines more advanced in considering leadership as an important aspect of the field, namely, industrial engineering and civil engineering. Authors hypothesize that the evolution in these fields is due to the high interpersonal demands between engineer and stakeholders in practice, as well as the close relationship between both fields and project management and business. Other areas are void of the topic, yet calls for reform are across the board in engineering educational institutions.

Deeper analysis across disciplines reveal key insights within each category of research questions. For the first category, Definitions/Descriptions, Fig. 2 identified the count of competencies discussed across the various disciplines as important for engineering leaders. Not surprisingly, the top competency mentioned throughout the articles was communication. Some articles suggest communication as in verbal presentation or writing skills, while others suggest communication as it related to interpersonal and relationship management. As engineering leadership education has evolved, it is important to note the differences in communication needs of graduates. Earlier articles focused on a more formalized, traditionally professional need for communication centered on writing and presentation skills. Later articles focused more on the interpersonal/relationship management aspects of communication and mention the need for emotional intelligence. This finding aligns with Handley and Berdainer's adaptive communication competency for effective interpersonal behaviors for engineering leadership [79]. These findings suggest that communication skills that encompass interpersonal communication and behavioral considerations may be a key aspect of engineering leadership curricular adaptations.

For the Education/Training Methods category, the techniques largely remained rooted in experiential, service, and project-based learning, reiterating the perceived need to practice engineering leadership within the context of an engineering project, rather than solely focusing on theoretical concepts. These techniques were most often built into upper level capstone projects, and were frequently paired with seminars, workshops, and other activities to introduce or bolster leadership competencies. Other extracurricular activities and methods were discussed in the literature, but these prove challenging towards fulfillment of accreditation criteria, as they are often not mandatory of all students in a program. Because of the variety in structures, curricula, and requirements across engineering programs, authors suggest that a single model will not fit all programs but that the field could evolve more rapidly if there were some level of standardization among program elements and assessments.

Further, the assessment category revealed a trend of applying existing validated leadership instruments in an engineering education context, rather than developing targeted assessments specifically for engineering leadership. This area of the literature review returned the smallest number of studies. While Civil Engineering has more in this area specifically applying leadership theory to leader performance in the industry, overall assessment of leadership is lacking- whether assessment of individual, programmatic, or evaluation of programs implementing leadership. Validated assessment of

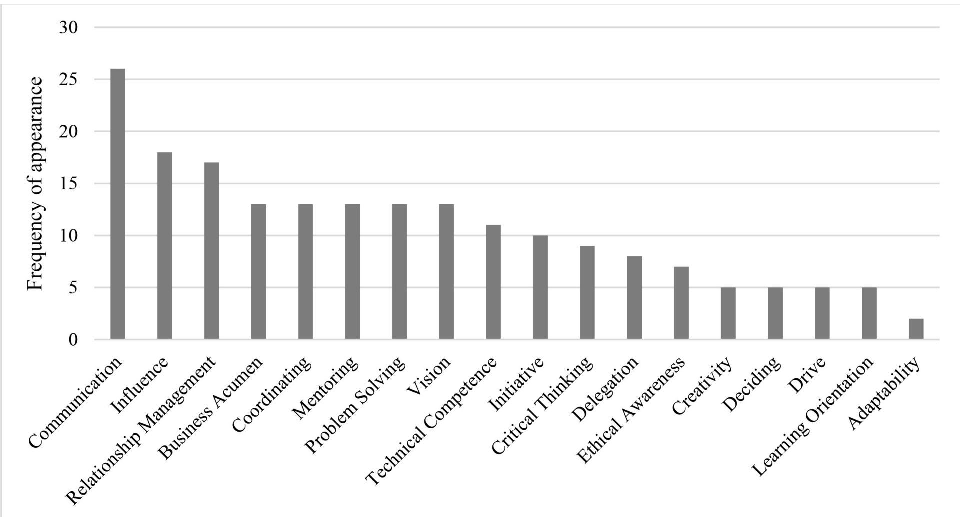

Fig. 2. Frequency of appearance of competencies described as important for engineering leaders.

student leadership development and evaluation of programs/courses is the next evolution of engineering leadership research. Given the general consistency between the leadership competencies described above with common definitions of leadership, there may be merit in leveraging and validating existing instruments as a starting point for leadership assessment within the profession before developing novel measurement techniques. This would lay the foundation for more consistent assessment techniques of the breadth of education and training methods, ultimately helping to identify best practices more objectively in developing engineering leadership attributes, skills and competencies.

5. Conclusions

Leadership has become increasingly identified as a critical skill for engineers by both industry and accrediting bodies. This study sought to survey the existing literature to identify (1) what are definitions or descriptions of leadership attributes, competencies, and skills (2) what assessments are being used within each discipline, and (3) what types of education or training methods are being implemented. The systematic literature review highlighted a large disparity in frequency of studies on engineering leadership among the various engineering disciplines explored.

The authors categorized skills and competencies discussed in the papers they reviewed in alignment with 18 attributes determined through a literature review in advance of the study. Though the attributes, competencies, and skills varied within each discipline, ''communication'' appeared most frequently across disciplines and studies, with ''influence'' and ''relationship management'' following as the next highest frequency items. Most education and training methods identified had a project-based component, oftentimes paired with a theory-based curriculum. Most commonly, these methods were integrated as part of an upper-level capstone course. The study of the assessments being implemented within each discipline identified the greatest opportunity for growth within the field of engineering leadership. The literature on engineering leadership assessment is sparse, disjointed, and the majority of assessments used were not well validated. Additionally, authors see opportunity for growth in engineering leadership in some underrepresented disciplines. Workforce and educational needs related to leadership should be explored in these disciplines. Implementing validated assessment tools and methodologies across existing programs stands to strengthen existing programs and help build objectively more valuable educational experiences for the field of engineering leadership.

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