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Work In Progress: But Wait! Design and Leadership Competencies Are More Similar Than You Think!

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Abstract

Design has historically been a key topic taught broadly in engineering education programs, while the topic of leadership development in engineering education programs is relatively new. This paper will summarize the findings of a scoping literature review on design competencies, leadership outcomes, and the intersection of the two in an engineering education setting. Research in design courses shows that topics commonly covered include professional skills, teamwork, project management, productive communication, and ethics in addition to technical knowledge. Similarly, research on engineering leadership development has summarized a list of outcomes such as communication, teamwork, vision, interpersonal skills, ethics, organization, decision making, and time management in addition to technical knowledge. These observed similarities in outcomes of the two domains (communication, teamwork, ethics, etc.) motivated the work of this paper.

To investigate the synergy of these two domains, a scoping literature review was conducted with the intention to identify areas of intersection in the engineering learning outcomes for design and for leadership and to simultaneously summarize the points that clearly differentiate the two concepts. This Work in Progress scoping literature review starts the exploration of these concepts side-by-side with results and analyses driving future studies.

Background

Engineers of future generations have the opportunity to play a significant role in shaping the impact of technology on the daily lives of average people. In order to prepare engineering students for a future that is unknown, engineering education must prepare graduating students to be adaptable, motivated, and creative problem solvers who are aware of the broader context of engineering challenges and solutions. These challenges provide the opportunity for future engineers to leverage both their design and leadership abilities together to address them. Design, as a foundational part of engineering, provides a means for engineers to practice creative problem solving and has been taught in engineering programs for generations. Newer interest in developing leadership competencies among engineering students is driven by professional organizations such as ABET, ASCE, and ASME [1-3].

Leadership has been identified by professional organizations and ABET as an integral skill for engineering professionals to practice and for engineering students to learn in order to address the future needs of society [1]. According to the National Academy of Engineers [4], the complex sociotechnical aspects of engineering practice must be met with engineers who are prepared to work within them. Leadership development is an important aspect of an engineer’s preparation to meet the responsibility of solving tough environmental, infrastructure, healthcare, and transportation problems while realizing the ethical and humanistic impacts of engineering decisions.

However, research shows that working engineers do not always view engineering as a leadership profession – Rottmann et al. found that when engineers' understanding of leadership aligns with traditional, vertical leadership (one leader at the top of an organization), they are less likely to self-identify as a leader or to identify their colleagues as leaders [5]. Furthermore, many engineering faculty do not feel prepared to teach leadership to engineering students [6]. Yet, Knight & Novoselich [7] found that students believed leadership education more impactful when it was taught within required curriculum, leaving broad opportunity for integrating leadership development concepts into the required courses taken by engineering students. Plus, leadership is best taught in context, such as in a group setting where the group shares a set of goals [7]. Design courses provide a prime opportunity for students to integrate their leadership and engineering skills development.

There is a history of considering design and leadership as two distinct domains, with respect to both the teaching and researching of these topics. However, at first glance there are stark similarities between the list of leadership competencies (communication, teamwork, vision, interpersonal skills, ethics, organization, decision making, and time management, along with technical knowledge) and the learning outcomes of design courses (professional skills, teamwork, project management, productive communication, and ethics, along with technical knowledge). In the engineering education community, however, there have not yet been substantive conversations about the convergence of these two domains. Overlapping these complementary competencies and reframing the role of leadership within design, noting commonalities of the two, could provide a pathway for engineering design faculty to integrate explicit leadership development teaching methodologies (through small intentional changes) into their courses in a way that compliments current required curriculum.

The purpose of this study is to find the overlapping competencies of teaching engineering design and engineering leadership in higher education, as well as to understand where the two domain competencies do not overlap. The authors do not posit that all leadership competencies can be taught through design courses, yet we believe that a subset of leadership competencies are already being taught through engineering design education yet are rarely identified as "leadership." Creating awareness of the commonalities in design and leadership competencies has the potential to encourage design faculty to more explicitly discuss leadership along with design in their courses. This helps create a stronger culture of leadership within the engineering profession, builds student engineering leadership identity, and empowers future engineers to address emerging engineering and societal challenges.

This brings us to the research question: what competencies does past research identify as being common and different between the engineering design and engineering leadership domains?

Definitions

Because this paper explores competencies from different areas of engineering education research, setting clear definitions for our key terms is important. The following sub-sections outline the definitions of competencies, engineering leadership, and engineering design that were used by the researchers for this paper.

Definition of Competency
The term competency has a history of being studied in the field of psychology and was made more prevalent in research and practice in the 1970s by psychologist David McClelland [8]. Since then, various authors have defined competencies - the definition from Spencer and Spencer [9] is as follows: competencies are “motives, traits, self-concepts, attitudes or values, content knowledge or cognitive or behavioral skills - any individual characteristic that can be measured or counted reliably and that can be shown to differentiate significantly between superior and average performers or between effective and ineffective performers” (p. 4).

Definition of Engineering Leadership
The MIT Gordon Engineering Leadership Program defines engineering leadership as “capabilities and values that transform technical people from individual contributors into those who can lead teams to *deliver* a complex multi-disciplinary product. Leadership is a process and there is a two-way relationship between the leader and the team … Leaders inspire and influence teams to accomplish things that they otherwise would not have done on their own” [10]. Current thinking on engineering leadership acknowledges that leadership is not limited to the contributions of one team member. In addition, various articles have found that in engineering student design teams, such as capstone design, shared leadership is common [11]. Shared leadership is defined as “a dynamic, interactive influence process among individuals in groups for which the objective is to lead one another to the achievement of group or organizational goals or both” [11, p. 1].

Definition of Engineering Design
ABET defines engineering design as “a process of devising a system, component, or process to meet desired needs and specifications within constraints. It is an iterative, creative, decision-making process in which the basic sciences, mathematics, and engineering sciences are applied to convert resources into solutions. Engineering design involves identifying opportunities, developing requirements, performing analysis and synthesis, generating multiple solutions, evaluating solutions against requirements, considering risks, and making trade-offs, for the purpose of obtaining a high-quality solution under the given circumstances” [1].

The authors noted that each definition was articulated as a process for the purpose of creating or accomplishing products and solutions. Atman et al. [13] characterizes the engineering design process as consisting of three categories: work process, cognitive process, and social process. The definitions of engineering leadership, both at MIT [8] and in the shared leadership in engineering literature [11], touch on the concept of engineering leadership also being a social process, or the interaction and influence between individuals.

Methods and Results

As the researchers decided to explore this research question, they sought to further understand how these two domains within engineering education are understood and researched in pursuit of learning how the competencies of each are articulated. To do this, they decided to use a scoping literature review, a style of literature review useful in exploring and clarifying the “conceptual boundaries” of a topic, according to Peters et al. [14, p. 141]. Scoping reviews are more general than systematic reviews [15] and are termed as a type of “reconnaissance” by Peters et al. [14, p.

141]. A scoping review is appropriate for an early-phase exploration of research domains, such as a work-in-progress paper, and can be used to identify appropriate inclusion and exclusion criteria for future full systematic reviews [15].

With engineering leadership as a relatively nascent field and engineering design's obvious place within the actions of the engineering profession, the researchers planned to embark upon two scoping literature reviews. One review was to explore what previous work has identified relative to engineering leadership competencies and the second review would explore the previous research related to engineering design competencies. The resulting search found that a systematic literature review had been recently completed for the engineering leadership domain [16], as is further described in the next paragraph. We decided to use this pre-existing material to address our research question. Next, we completed the scoping literature review for the engineering design domain. Then, the results of the reviews in each of these two domains were compared to determine where commonalities exist and to identify the competencies that did not overlap.

Engineering Leadership. As the scoping literature review was started for engineering leadership, the researchers quickly discovered a full systematic literature review of engineering leadership competencies had recently been completed. Handley et al. [16] performed a systematic review of peer-reviewed articles that address engineering leadership in post-secondary education and professional contexts that highlighted leadership "attributes, competencies, and skills" (p. 313) across typical disciplines in engineering. Twenty-nine articles were included in identifying these factors, from aerospace, biomedical, chemical, civil/construction, computer/computer science/electrical, industrial, and mechanical engineering. The largest number of articles came from mechanical engineering. The competencies that were found by this engineering leadership systematic literature review are listed in Table 1 and provide a foundation for our comparison with engineering education design competencies.

Engineering Design. In the search for engineering design, the authors utilized the Engineering Village database and found over a hundred thousand articles using the search terms "engineering design" or "capstone design" or "senior design." When the search term was refined to "engineering design outcomes" or "engineering design competencies" or "engineering design skills" 97 articles were found. However, in an initial analysis of the top 20 papers from the list, the researchers did not find a research-based clear list of engineering design competencies. The body of knowledge related to engineering design lacks a comparable paper to the Handley et al. article, which comprehensively surveys engineering papers for engineering leadership competencies [16]. The top sources that came up in this search had focus areas that were adjacent to, but not exactly aligned with, the goals of this study - often they focused on individual skill building rather than broader competencies.

A group of articles had a focus on the broad pedagogical method of project-based learning (PBL) [17-20]. Dym et al.'s seminal paper *Engineering Design Thinking, Teaching, and Learning* established PBL as the preferred pedagogical method for teaching design in engineering [21]. However, the researchers determined articles with a focus on primarily PBL should be excluded from this study at this phase of research. Determining which PBL articles are specific to design competencies was beyond the scope of this exploratory project but could be integrated into a future systematic literature review.

A conference paper identified the benefit of other very specific skills such as spatial visualization and sketching [22] on general design outcomes that were not defined. The authors recognized that research on specific skills can be mapped to engineering design competencies and these articles were noted for inclusion in a full review. One article outlined only the process of design and the identified solutions rather than focusing on the comprehensive set of engineering design outcomes learned [23] during the process. At this point, this subset of papers was flagged for exclusion from a full review due to the difficulty connecting to engineering design competencies. This search forced us to acknowledge the challenge of identifying research work that focused on engineering design competencies rather than skills. Because a scoping review is appropriate for determining which inclusion and exclusion criteria are warranted [15], we chose to focus this paper on engineering design competencies rather than specific skills at this time. However, we see the opportunity for including engineering design skills in a future systematic literature review.

Another conference paper found in the scoping review of engineering design competencies was relevant to our exploration. Goff and Terpenney [24] summarize the results of an affinity-type exercise among engineering design education thought leaders and researchers where they identified their opinions on the most important design competencies. They posted their ideas on white boards and refined ideas during the course of the Harvey Mudd Design Workshop in May 2011. Their eight high-level competency categories are personal attributes, evaluation and testing, creativity, problem and opportunity identification, communication and teamwork, knowledge creation and thinking processes, making things, and technical fundamentals.

One of the few journal articles that focused specifically on identifying and listing engineering design competencies is situated in the professional engineering context at an aerospace design engineering firm [25]. The article uses more rigorous research methods: initial interviews, questionnaires, then Critical Incident Technique interviews to identify design engineering competencies into the next decade. The design competencies identified in the study are listed in Tables 1 and 2.

To provide as close to an "apples to apples" comparison of the engineering design and engineering leadership domains as possible, we decided to focus these results on the two journal articles that had rigorous research methods and the clear purpose of identifying competencies that align with each of these areas - the engineering design study done in the professional setting by Robinson et al. 2005 [25] and the systematic review of engineering leadership competencies done by Handley et al [16].

Summary of Results

The competencies for both leadership and design are listed in the tables in sub-processes, which align with the three viewpoints of engineering design practice identified in the Cambridge Handbook of Engineering Education Research by Atman et al. [13]. Atman et al.'s research identified three engineering viewpoints to describe engineering design practice: work process, cognitive process, and social process. This categorization summarizes engineering design conversations and research that directly impacts how we think about engineering design pedagogy and how engineering students learn the complex craft of engineering design [13] and proves to be a useful way to organize the competencies identified here.

Table 1 highlights the common competencies listed in the Robinson et al., [25] and the Handley, et al. [16] studies. Competencies that were the same or similar are matched in the rows. For example, the design competency of “works hard” is matched to the leadership competency of “drive.” Thirteen attributes/competencies identified by these two sources are identified as shared between engineering design and engineering leadership. In the table, they are categorized in alignment with the categories of engineering design process identified by Atman et al., [13].

Table 2 identifies the attributes/competencies that are distinct between the two sources and has a similar method of organization. Competencies are not matched between columns.

TABLE 1
ENGINEERING DESIGN AND ENGINEERING LEADERSHIP COMMON COMPETENCIES BY CATEGORY OF DESIGN PROCESS [13] AND MATCHED BY TOPIC

	Design [25]	Leadership [16]
Work Process	Is motivated	Initiative
	Works hard	Drive
	Project management	Business acumen
	Plans work	Coordinating
Cognitive Process	Copes with ambiguity	Adaptability
	Makes effective decisions	Deciding
	Thinks intuitively	Critical thinking
	Thinks ‘outside the box’	Problem solving, Creativity
	Is able to learn	Learning orientation
	Technical ability*	Technical competence
Social Process	Has good interpersonal skills	Relationship management
	Seeks support from others	Influence
	Communication*	Communication

*high level themes from Robinson study [25]; for these themes, sub-competencies are not included

TABLE 2
ENGINEERING DESIGN AND ENGINEERING LEADERSHIP DISPARATE COMPETENCIES BY CATEGORY OF DESIGN PROCESS [13]

	Design [25]	Leadership [16]
Work Process	Proactively seeks training Monitors progress Manages problems Manages time Conducts risk assessments Identifies factors	
Cognitive Process	Has job satisfaction Enjoys challenges Is assertive Is open minded Is self-confident Adopts a calm approach Stays focused Understands the task Judges importance Analyses tasks Learns from mistakes Seeks simplest solutions Thinks quickly	Vision* Ethical Awareness*
Social Process		Mentoring Delegation

*competency not matched with left column competency

Discussion

As shown in Table 1, there are numerous commonalities between the competencies of engineering design and engineering leadership, and various themes emerged from the comparison. There are overlapping competencies in each of the sub-process areas of the engineering design process. Various competencies align with work process, or how the work is approached, planned, and managed. The largest number of commonalities exist in the cognitive process section. These competencies align with how information is gathered, taken into consideration, and used creatively. Thirdly, both engineering design and engineering leadership value the social process of their domains, aligning on the importance of communication and positive influence during social interactions.

The processes of engineering design and engineering leadership both require fundamental technical skills, making this a common theme between these two domains and the factor that differentiates both engineering leadership and engineering design from leadership and design in other fields. Engineering design and engineering leadership draw on or overlap with many other similar fields but are unique in the specific technical skills required of their practitioners.

The competencies that were different between the two domains are shown in Table 2. Although not specifically matched based on these two articles, various aspects of the design competencies related to personal behaviors could be interpreted as aligning with leadership behaviors as well: enjoys challenges, is assertive, is open-minded, is self-confident, proactively seeks training, and adopts a calm approach.

The skills identified as only being part of the leadership competencies are mentoring, vision, delegation, and ethical awareness. These areas are core to the domain of leadership development, but design courses also provide ample opportunities for students to practice these behaviors. In student design teams, often some students are more experienced at various phases of the design process and mentor (lead) other students in those areas. Defining a clear design problem with a clear rationale aligns with setting a vision; delegating tasks is important in any project, even when leadership is shared among various team members (as it is likely to be in a peer-led design project in an engineering education setting). Ethical concepts are often taught in leadership courses and are often integrated into the design decisions made by a design team. This suggests that while teaching design skills, instructors are also teaching and reinforcing leadership development among engineering students.

Recommendations for Faculty Members

The fact that these results highlight the significant overlap between design competencies and leadership competencies is meant to give design faculty members something to consider and discuss when developing their courses. In teaching design, many faculty members are already teaching toward a significant number of leadership competencies. While the description of these learning outcomes may be "professional skills" or they may be implicitly taught, they align with many stated engineering leadership competencies. Small changes such as re-contextualized rationale (to include leadership vocabulary) to explain why various behaviors are beneficial to a design team or a professional engineer may have significant impact in positively developing engineering leadership identity in engineering students. Engineering leadership identity may be created through the process of becoming personally aware of leadership concepts and then developing specific leadership skills which could lead to the recognition of oneself as a leader [26]. This cycle of leadership identity development will be aided when faculty directly acknowledge the skills and competencies learned in engineering design courses as helping to build leadership competencies that will benefit students in their future careers.

This reframing of engineering leadership as a significant factor in engineering design (e.g., using the words *leadership* when discussing shared responsibilities such as roles on a design team [27], or in project management) could be extremely impactful in changing the mindset of engineering students to think of themselves as leaders and/or to acknowledge their leadership potential and opportunities in future employment settings. People with the technical knowledge to solve problems should be the people making the decisions about how they are solved, and the further integration of engineering leadership development can empower engineering students to take on these challenging responsibilities.

Limitations and Suggestions for Future Research

This scoping literature review is not comprehensive or systematic but seeks to identify inclusion and exclusion criteria for future full literature reviews. Therefore, a limitation of this paper is the exploratory approach and the relatively low number of papers that were reviewed as part of this initial study. Therefore, the results in the Discussion section should be validated with future work. However, the intent of this paper is to start the conversation on the relationship between engineering leadership and engineering design competencies and seed future work that is more in depth and actionable.

For future research, we recommend a full literature review of individual skill development in engineering design courses and a mapping of these skills to competency categories. This type of study will then allow more detailed comparison to engineering leadership competencies. Additionally, a full literature review of pedagogical approaches that research has identified as causal for the development of skills and competencies in leadership and design could provide actionable steps to the engineering leadership and design communities.

Conclusions

Significant team-based design projects cannot be run without students using skills that align with leadership competencies, and leadership is best learned in an authentic context. Engineering design and engineering leadership competencies overlap significantly, highlighting the opportunities that exist in teaching leadership explicitly in design courses. Teaching leadership within the context of design projects is a relatively low-effort high reward practice that can help change the culture of engineering to one that encourages engineers to think of themselves and act as leaders in order to contribute even more to addressing the unpredictable challenges of the future.

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