Including Leadership in Civil Engineering Education

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Leadership in engineering is an important skill. The demands of engineering have changed due to rising global challenges and the need for leadership skills [1]. Global competence has been studied through a global mindset and social skills [2], [3] At the same time, the demand for engineers with leadership and technical skills is increasing. In a field where technical competence is traditionally valued over interpersonal and leadership skills, the deliberate development of engineer leaders is needed [4], [5], [6].

Although there has been debate about the ability to teach leadership, the ability to learn leadership skills has been shown to prepare those in leadership positions [7]. Some engineering curricula and professions deliberately incorporate leadership [8]. The need for an engineer leader is visible with the increased need for problem-solving. Leadership training has been included in engineering education through specific learning approaches. Leadership has been included in the curriculum in the classroom [9], [10] through capstone courses [11], [12], and also through service learning [8], [13].

The needs of the civil engineering career field are evolving due to the changing demands. Leadership skills for engineers are in demand [14]. In this work, we discuss leadership development in undergraduate Civil Engineer education. Students are prepared for leadership challenges by developing them in a curriculum incorporating leadership challenges throughout the program. Leadership levels and types of leadership learning vary from learning interpersonal skills to leading small and large teams. Delivery methods include guest speakers, hands-on learning, capstone, and full-scale events with specific objectives. Multiple opportunities are provided for personal leadership, group leadership, and team leadership. Leadership responsibilities and expectations are increased over time.

Learning leadership is an iterative approach requiring multiple experiences at different levels [15]. This work explores leadership theory and practice in civil engineering education through a holistic approach using a combination of methods. The framework used here may serve as a framework for other institutions examining incorporating or implementing leadership in programs.

Leadership Outcomes

Leadership is an integral part of education at the US Air Force Academy (USAFA). This leadership is ubiquitous in all functions at USAFA including the Civil Engineer major. Civil Engineer majors will graduate and enter various career fields all with the expectation that they will be leaders. The nine institutional outcomes define the goals for students to work toward improving. The objective of this paper is to explore leadership theory and practice in civil engineering education through a holistic approach using a combination of methods. The framework used here may serve as a framework for other institutions examining incorporating or implementing leadership in programs.

Overall, USAFA works to instill outcomes for graduates to work towards including:

(1) Critical Thinking
(2) Application of Engineering Problem-Solving Methods
(3) Scientific Reasoning and Principles of Science
(4) The Human Condition, Cultures, and Societies
(5) Leadership, Teamwork, and Organizational Management
(6) Clear Communication
(7) Ethics and Respect for Human Dignity
(8) National Security of the American Republic
(9) Warrior Ethos as Airmen and Guardians

The fifth institutional outcome describes the leadership outcome, for students to exhibit leadership, teamwork, and organizational management. These outcomes are similar to the National Association of Colleges and Employers (NACE) eight core competencies. NACE includes career and self-development, communication, critical thinking, leadership, teamwork, technology, etc as a part of their career competencies. These competencies have been studied for inclusion in engineering courses[16]. Including leadership training has been shown to increase self-development, critical thinking, and teamwork [17], [18]. This work takes a broader look at a Civil Engineering program.

The leadership institutional outcome is implemented with a leadership model used at USAFA. The PITO model, introduced by Cycyota et al., 2011, the model is used for students interested in leadership to develop their skills through various levels. The major includes leadership in various methods from interpersonal, and self-reflection, to large teams to provide a multitude of leadership opportunities in numerous arenas where the personal, interpersonal, team, and organization (PITO) model is the framework for leadership. The model begins with personal leadership, builds interpersonal leadership, followed by team leadership, and culminates with organizational leadership. Personal leadership focuses on mastery of primary duties, personal awareness, followership, and leading by example. Interpersonal leadership focuses on the ability to coach others, effective communication, and develop planning skills. Team leadership is characterized by the ability to use team dynamics, understand how to make decisions, and hone supervisory skills. Finally, organizational leadership focuses on using influence to help a unit, recognizing and developing the skills of others, and professional standards [19].

The major program follows this same PITO model beginning with personal and interpersonal leadership stages. The three methods used in the Civil Engineering program are competitive small teams, senior seminar, and large teams. Also, many of the courses have projects nested

within them where students work together to lead each other as they complete the projects. After each feedback is given through comment cards, group assessment, or self-assessment. Competitive teams such as capstone, steel bridge, and concrete canoe teams use the small team leadership concept. The next method is Senior Seminar with speakers demonstrating the need for leadership and professionalism in engineering. Finally, hands-on leadership through courses such as the Field Engineering Readiness Laboratory (FERL) and Senior Leadership Exercise demonstrates large team leadership to accomplish a shared goal. Figure 1 shows the buildup of leadership skills throughout the Civil Engineer student's journey.

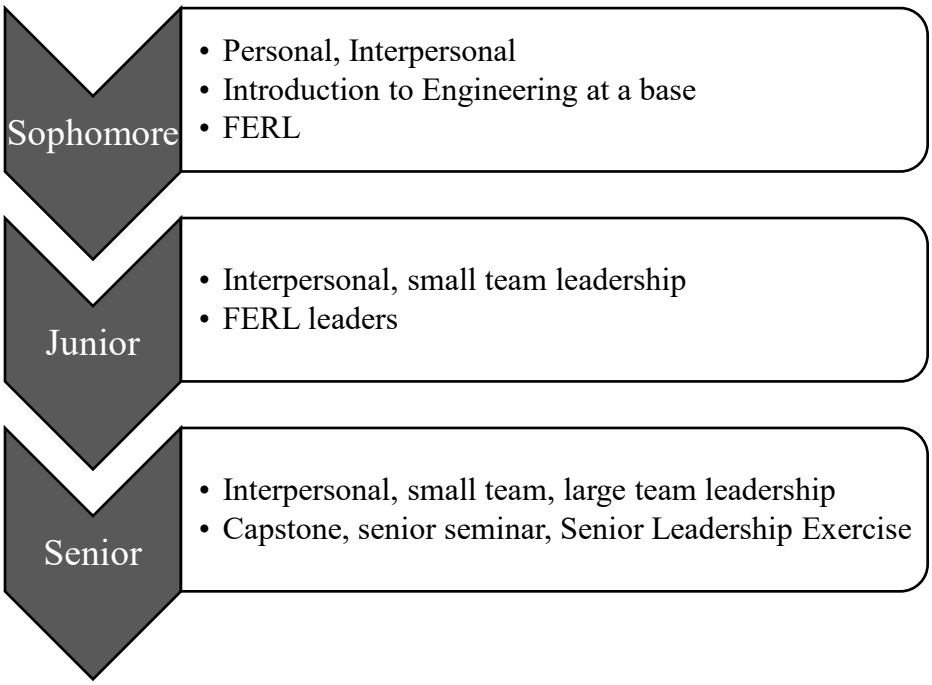

Figure 1: Leadership Development in the Civil Engineering Program

Civil Engineering Curriculum

During primarily the last two years of a student's time, the Civil Engineering major will participate in major-specific leadership events. Over the summer, sophomores will practice personal and interpersonal leadership in their coursework and through the FERL program [13]. As students are in their junior year, they transition to small team leadership by leading small teams or flights of 10 students becoming leaders in the FERL program. Finally, seniors will demonstrate interpersonal leadership, and small team leadership, and add leadership of larger groups in exercises such as the Senior Leadership Exercise (Firstie Flag). Senior students also work in small teams for capstone projects which include experiential and hands-on learning. The subsequent section will describe each of these events in greater detail. Figure 2 shows the variety of methods used in developing the leadership skills of Civil Engineering students.

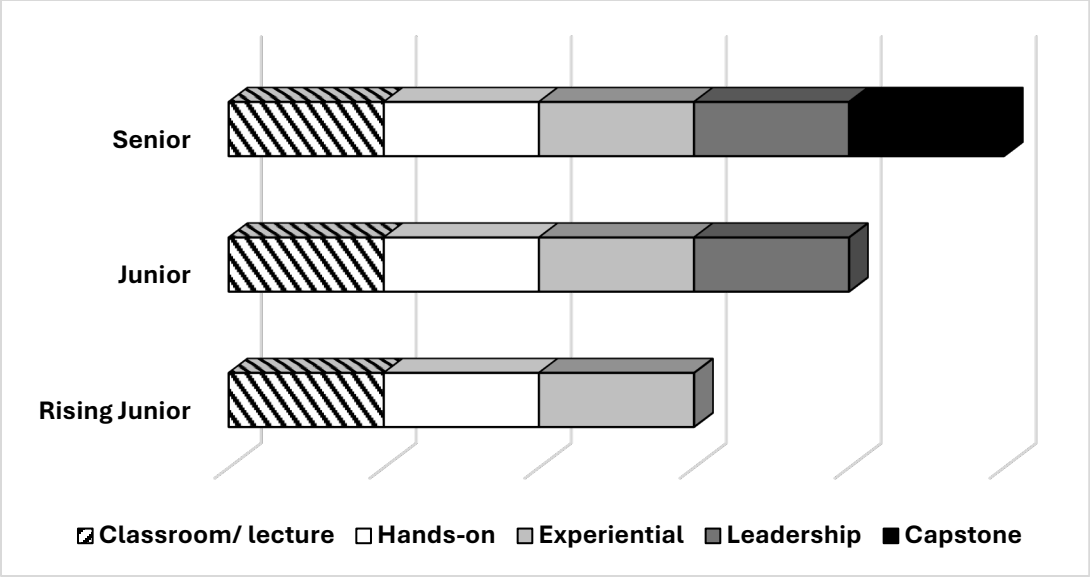

Figure 2: Leadership Types by Year

FERL

The FERL program is a summertime program for sophomore students to experience engineering through a hands-on approach. Students have had one or two introductory courses in the major and this point and have some background knowledge in engineering. The motto "build first, design later" captures the idea of using intuition to build first and discover practical design by making mistakes first. Some lecture is included, but most of the activities are hands-on where students will use their basic knowledge to accomplish, but more importantly, learn. Some examples of hands-on activities include concrete mix & beam design, sprinkler design, materials testing, steel construction, and wood frame construction. The students are organized in flights where they follow their Student Flight Commander through activities. Feedback is given to students for participation and attitude for interpersonal development through understanding how they are perceived. The main objectives for the course include:

(1) Work in teams effectively to solve civil and environmental engineering problems.
(2) Describe the production, properties, behavior, and uses of common construction materials (soils, steel, concrete, asphalt, and wood).
(3) Describe various construction methods and techniques used in civil engineering.
(4) Describe roles and responsibilities of Civil Engineers.
(5) Describe broad environmental engineering concepts.
(6) Describe common civil and environmental engineering field and laboratory tests.

The first objective requires teamwork to solve engineering problems, capturing the teamwork for institutional objective five. The objective requires both personal and interpersonal leadership skills.

Many of the students who participate in FERL as a student will return the following year to lead underclassmen as the leadership team. The leadership experience as a junior student allows for

small-group leadership. The FERL leadership opportunity allows students to practice leadership and organizational management for institutional objective five.

Capstone

All senior students must participate in a capstone team during the year. Capstones can include competitive teams such as steel bridge, Associated Schools of Construction, and concrete canoe teams. Experiential research and design teams are also available to complete preliminary designs of buildings with user feedback, research on various problems, and design, testing, or construction of a simple structure. Each of these capstones is completed on a small team using hands-on and experiential learning. Course objectives include:

(1) Function as part of a design team.
(2) Apply the civil engineering design process and conduct iterative analysis and design of a solution to a challenging, ill-defined, and open-ended problem.
(3) Design a system, component, or process in more than one civil engineering context by applicable codes and regulations.
(4) Incorporate contemporary issues, such as economic, environmental, social, political, ethical, health and safety, manufacturing, and sustainability, as applicable to the solution of an engineering problem.
(5) Communicate and justify an engineering design through oral and written form.

Senior Seminar

The senior seminar course is targeted at senior students to learn from those with Civil engineering and leadership experience in the profession. This course provides mentorship and builds connections for students in their spring semester of the final year. This course provides some interpersonal reflection for students. Senior seminar's course objective is to develop a basic understanding of the civil and environmental engineering fields and learn how engineering fits into practice.

Senior Leadership Exercise (Firstie Flag)

Senior students preparing for leadership roles in the engineering community must be equipped to navigate complex scenarios, including operating in remote, resource-constrained environments under significant logistical challenges. To prepare for these realities, the Senior Leadership Exercise immerses students in a multidisciplinary, hands-on event that simulates the complexities of operational environments. This culminating experience builds on earlier leadership training, such as FERL and capstone projects, exposing future officers to expeditionary resources and challenges while reinforcing critical thinking, teamwork, and decision-making skills.

The exercise unfolds in two phases: academic preparation and hands-on implementation. During the academic phase, students collaborate across career fields to address a simulated Pacific conflict scenario where a hostile force has degraded infrastructure critical to a foreign partner. Senior engineering students must prioritize missions, identify operational requirements, assess residual capabilities, and plan resource deployments. Their objective is to design an optimal

layout for base camps and operations, ensuring mission success while balancing safety, efficiency, and speed.

Following their planning, students present their strategies to a senior authority for approval. These presentations demand clear communication, critical analysis, and leadership, as students explain how their plans address life-support activities, maintenance needs, and operational requirements. Once approved, students transition to the hands-on phase, where they execute elements of their plans by establishing support areas (e.g., sleeping and dining facilities) and operational sites (e.g., airfields). Senior students lead multidisciplinary teams, ensuring seamless integration across Civil Engineering, Security Forces, Logistics, and Operations.

This immersive experience synthesizes the engineering principles students have studied with the leadership skills they have developed throughout their training. By participating in the Senior Leadership Exercise, students learn to assess priorities, coordinate resources, and lead effectively in austere environments. These experiences equip them to face the challenges of deploying airpower and achieving mission success in their future roles.

Results

Students receive feedback iteratively throughout events including during each leadership event. Instructors will provide feedback to groups working on the project, which can include group dynamics. Formally, ABET student outcome 5 is evaluated specifically during FERL and the student's senior year capstone projects as a part of ABET requirements. Informal feedback is provided to the students during group activities such as FERL. The feedback allows the students to understand how they are viewed by others, including leaders of activities. The feedback matrix below is used to generate a rating provided to the student during each activity during the three-week FERL program. The feedback can prompt students to take more initiative or prompt a conversation with their leadership team about specific steps they can use to improve their leadership during the program.

10:	The student is a team player showing initiative with both the organization and the unit. In tune with the learning objectives of each activity. Willing to go out of their way to accomplish the goal. The student continually tries to improve the task, even at the end of the course. Work is of excellent quality. Communication skills are excellent.
9:	Takes initiative, goes above and beyond in area of work. All work done on time. Seeks alternative solutions without prodding. The student works hard to produce quality work. Communication is satisfactory.
8:	Reactive following instructions, but no extra effort. The student is not leading, rather following. No innovation involved in thinking. Does not seek leadership, but when commanded will lead. Work is acceptable. Communication is marginal.
7:	Narrow vision when asked to do something. Will agree but often does not follow through. Looking for the minimum to get by. Lacking initiative. Work is often late and at times is unacceptable. Displays a poor attitude in class or during construction-related activities.
6:	May sometimes purposely obstruct project progress, no appreciable or clearly observable/identifiable work or accomplishments, cannot be counted on, attempts to do other things in class, and is lackadaisical. The lack of interest in the class quite often negatively influences other class members.
U:	Unsatisfactory - Some level of behavior that warrants further action from leadership.

Figure 3: Example feedback rating matrix

During each activity, a peer assessment is also completed by each member of a small team on every other member of that small team. Student performance, attitude, leadership qualities, communication skills, and special contributions are listed for students to provide feedback to each other. Because the peer assessment is anonymous, the students can be honest in their feedback to fellow students.

Capstone advisors provide feedback to students on performance and specifically address teamwork and leadership. The teamwork outcome (figure 4) is included in the rubric and a graded outcome.

Civil Engineering Student Outcome	A	A-	B+/B	B-/C+/C	C-/ D / F
TEAMWORK. An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives	Exemplary in most areas: 1. Providing leadership 2. Creating a collaborative and inclusive environment 3. Establishing goals 4. Planning tasks Meeting objectives	Exemplary in two areas and satisfactory in all others: 1. Providing leadership 2. Creating a collaborative and inclusive environment 3. Establishing goals 4. Planning tasks Meeting objectives	Satisfactory or better all areas: 1. Providing leadership 2. Creating a collaborative and inclusive environment 3. Establishing goals 4. Planning tasks Meeting objectives	Marginal or better in all areas: 1. Providing leadership 2. Creating a collaborative and inclusive environment 3. Establishing goals 4. Planning tasks Meeting objectives	Not proficient in at least one area: 1. Providing leadership 2. Creating a collaborative and inclusive environment 3. Establishing goals 4. Planning tasks Meeting objectives

Figure 4: Capstone Assessment Rubric for Teamwork

Students receive feedback on their performance, and faculty ask students to provide feedback about each course and at the end of the program experience. When asked what enhanced the educational experience the most, students overwhelmingly wrote about the faculty in the program. The data from the student feedback shown in figure 5 shows the faculty is most impactful to the student experience. The next most impactful experience was FERL, followed by the capstone, then competition teams.

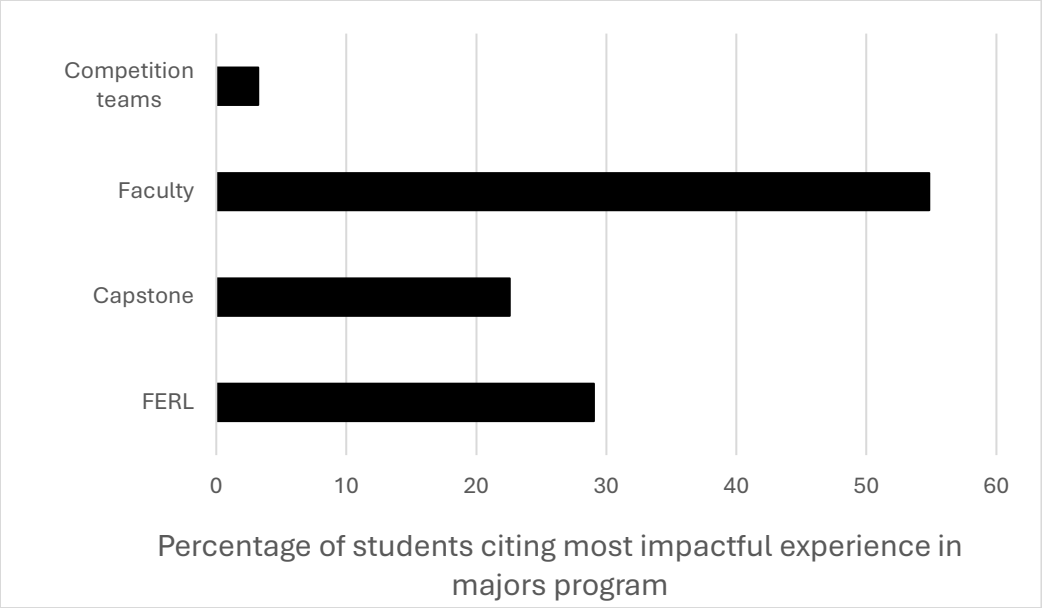

Figure 5: Percentage of students citing most impactful experience in majors program

The Civil Engineering major has a program for the deliberate development of leaders in the program. Many aspects of the development program are cited as useful to the student, but all of the programs described are led by instructors within the Civil Engineering major. The interaction of faculty members with students throughout the student's time in the major through FERL, capstone, team competitions, and courses resulted in positive outcomes for leadership learning.

Former faculty members now in academia and industry also provide regular feedback to the program on items to continue and areas to consider incorporating. This feedback stated to continue the FERL summer program, but to introduce the areas of research going on in the program to students during the FERL program so they can join in the research the following year. Recommendations included introducing new capstone options to give students more choice. Strengthening the ties to industry was also a recommendation that could provide feedback on what industry leaders are looking for in their rising leaders.

Summary

The Civil Engineering major uses the institutional leadership outcome as a guide in including curriculum leadership. The PITO model of leadership is followed to build leadership skills at various levels with opportunities presented throughout the student's time in the program. Leadership opportunities are used throughout the students' time in the sophomore, junior, and senior years including interpersonal leadership, small team, and large team leadership. The leadership opportunities tie in with courses such as FERL, capstones, and team events to allow various opportunities for leadership at various levels. Feedback to the student is provided by comment cards, group assessments, or self-assessments. These allow the student to understand their performance and improve iteratively. Many of the programs contributed to the development of engineering leaders; however, the faculty in this program was cited as the most impactful to the student experience.

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