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Construct First, Design Later – Evolution over the past 25 years

Brad Wambeke (Academy Professor)

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The Civil and Environmental Engineering Department at the United States Air Force Academy has been providing a comprehensive "hands on" introduction to its civil and environmental engineering curricula for over 25 years. This introductory course is required for rising juniors within the program, and involves an immersive three-week summertime opportunity for students to learn applied civil engineering skills in a field environment while working under the guidance of industry experts. The course covers multiple sub-disciplines of civil and environmental engineering, and concludes with students constructing homes for a nearby community. The hands-on learning experience in the course provides a practical framework for the analysis and design courses that are taken later in the program. This purpose of this paper is to discuss the assessment-based changes that have occurred throughout the course's history and describe how the "construct first, design later" philosophy has been successfully integrated throughout the program. It also serves as a potential model for other programs interested in developing a similar type experience.

Field Engineering and Readiness Lab Overview

In 1994 the Department of Civil and Environmental Engineering at the United States Air Force Academy initiated an innovative concept in higher education: The Field Engineering and Readiness Laboratory, more commonly referred to as FERL. FERL is a direct result of the vision and dedicated effort of Retired Brigadier General David O. Swint to improve the learning of students in this unique course. FERL is where engineering practice and education are uniquely combined in a hands-on construction environment. In addition to improving the learning, FERL was intended to increase interest in and motivation to study civil and environmental engineering. Vander Shaaaf and Welch [1], and Buchholtz and Vander Schaaf [2] looked as several summer programs that were intended to create interest and increase student knowledge of engineering, and found students who attended FERL had a very positive experience. Each summer, rising civil engineering juniors engage in this cornerstone of their major's curriculum, a three week field course designed to introduce the students to their discipline and to lay a foundation for their subsequent coursework. Air Force Academy cadets are joined by other students from across the United States. The students are led by seniors who have previously taken FERL, and are instructed by Air Force Academy faculty, visiting professors, and most importantly, enlisted craftsmen and technicians from throughout the Air Force, and include members from the Active Reserve, National Guard, and civilian components. This student-centered program with NCO mentorship is not only a unique educational experience, but a valuable leadership laboratory. The FERL course provides essential background knowledge that integrated into the overall curriculum, as described by Jenkins, et al [3]. The goal of this paper is describe how the FERL program has been integrated throughout the civil engineering program at the USAFA, and to potentially serve as a model for other institutions interested in establishing a similar type program.

One way in which FERL breaks the mold of traditional education is through its unique "construct first-design later" approach. Traditional education consists of classroom lectures and labs followed by application in the field following graduation. FERL is a significant hands-on program where students participate in actual construction activities before learning about the theory behind the design and construction in the classroom. The authors would categorize FERL as a combination of an Experiential, Inquiry Based, and/or Project-Based Learning type of course, in that students are exposed to learning activities and that require them to apply their newly gained knowledge in a problem solving context. Kotatski et al [4] conducted a review of literature related to project-based learning, and found that balancing instruction with independent inquiry and effective group work were two essential elements for successful project-based learning. The authors feel the FERL program has these two elements, along with strong support from students and the faculty. The FERL course is centered on six learning objectives (listed below) and has nearly 20 activities that are related to the four sub disciplines of civil engineering that are included in the program. Several activities are associated with surveying, roadway paving, concrete beam construction and testing, wood frame house construction, heavy equipment operations, steel bridge erection, pipe and open channel flow design, expeditionary wastewater treatment and field trips to material and processing plants in the local area. A full list of activities is included in Table 1. These activities allow the students to assume the role of technician under the watchful eyes of mentors. In the following two years of classroom academic work, students can relate their theoretical classroom education to real-life construction experience gained during FERL. The six FERL course objectives are:

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

Table 1: FERL Activities

Construction	Environmental	Geotechnical	Structural
Wood Frame Building Construction	Water Treatment	Concrete/Asphalt Plant Field Trip	Concrete mix design
Intro to Surveying	Environmental Field Trip	Roadway Development	Concrete beam design
Total Station Surveying & GPS	Sprinkler Design	Geotechnical Activities	Steel Construction & Fabrication Shop Field Trip
Construction Site Visit	Open Channel Flow and Three Reservoir Problem	Heavy Equipment Operations	Material Testing
Power Production Operations	Stream Sampling		Concrete Placement & Finishing (Pad)

Several of the activities from Table 1 are described briefly to provide some context. As an example, one of the first week activities involves casting a reinforced concrete beam. Students are given form work, rebar, and supplies and told they will receive half a cubic yard of concrete in two hours. They are tasked to construct the strongest beam they can without extensive lecture about the design. After placing the concrete in their forms and a seven-day cure, the beams are tested to failure and various beam strengths and failure modes are examined. Instructors then help the students relate how their choice in rebar placement and beam dimensions affect performance, and what is typically used in design. Observing how their beams performed, students then begin to learn about important principles in reinforced concrete design, principles that will be expanded upon in classes later in the curriculum. It has been a great way for students to gain experience and to receive an introduction to the interaction between the reinforcing steel and the concrete. When the students later take a reinforced concrete design course, they can relate back to their experience at FERL. Seeing a concrete beam physically fail also highlights the professional and ethical responsibility they will bear as designers of structures used by a public trusting in their technical competence.

In addition to the concrete beam, the other FERL activities are integrated both with FERL and into the academic classroom. For example, cadets perform surveying activities throughout the program's three weeks beginning with auto-level exercises progressing through total station methods and ending with global positioning system surveying. This background greatly increases their understanding of topographical drawings and site plans used in later courses.

In heavy equipment operations, students experience the fundamentals of using various types of heavy construction equipment. This allows a greater understanding of both the skills required to operate such equipment as well as cycle times and equipment efficiency. These concepts will be studied further in subsequent construction management classes.

In the roadway development activity, students use their newly acquired skills in heavy equipment operation and surveying, establishing grade lines for a road way, installing a base course, and then paving with asphalt. All of this done under the watchful and helpful eyes of the mentors.

In addition to teamwork, physically erecting heavy steel components into a bridge structure give students insight into how plans and specifications become reality in the field. Reading construction drawings, constructability and safety are all important issues students learn about in this activity.

Students learn and apply basic hydraulic principles in the sprinkler activity using design curves to install a system that minimizes materials used while providing maximum water coverage, introducing them early on to the concept of sustainability. Additional environmental activities include open channel flow, the classic three reservoir problem, water treatment activities and an air sampling exercise that encourages them to link job site air quality to safety. All of these concepts are then reinforced in their junior year as they learn the fundamentals of hydraulics and environmental engineering.

Most of these activities would not be possible without the expertise and experience of mentors who work side by side with students. The mentors are a significant contribution to the unique value of FERL. Typically the mentors are technicians who guide the students through various crafts while allowing the students to actually perform the work. Carpenters, heavy equipment operators, plumbers, electricians, and surveyors come from throughout the active duty Air Force, Guard, and Reserve to work with the students and demonstrate first-hand how to function on multidisciplinary teams to accomplish project goals. In addition to supplying technical expertise for the Field Engineering and Readiness Lab projects, the mentors serve as excellent role models of the enlisted corps for the cadets who get to see the NCOs and airmen in the field work environment.

Assessment:

Like most courses, students are assessed on the different activities by a variety of means, and those assessments contribute to the assessment of the six course level objectives. Additionally, the course objectives contribute to the seven ABET student outcomes as shown in Table 2, and are incorporated into the overall program assessment. The intent of the paper is not to discuss the specifics of the assessment, but rather demonstrate that the FERL course objectives are associated with many of the student outcomes. The student outcomes describe what students are expected to know and be able to do by the time of graduation. These relate to the knowledge, skills, and behaviors that students acquire as they progress through the program. The seven ABET student outcomes [5] are:

1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors

3. an ability to communicate effectively with a range of audiences

4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts

5. 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

6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions

7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Table 2: FERL Objectives cross-referenced to ABET Student Outcomes

Civ Engr 351 (FERL) Course Objective	ABET Student Outcomes						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1. Work in teams to solve problems	x		x		x		
2. Describe common construction materials	x			x		x	
3. Construction methods & techniques	x	x		x			
4. AF CE roles & responsibilities				x	x		x
5. Environmental engineering concepts	x	x		x		x	
6. Field and lab tests	x				x	x	

The course has also used student feedback after each iteration, and that feedback has been instrumental in decisions related to assessment-based course changes. Many of the activities have remained fairly consistent through the years, but the wood frame activity has evolved significantly. The wood frame activity initially involved projects such as pavilions, garages, and classrooms that were used to add to the FERL site infrastructure. In the late 1990s, a decision to change the wood frame activity was made based on student feedback and an internal program assessment to better support the old student outcome (c), which was related to "an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability." The focus in the late 1990s was to better incorporate social considerations into the course. The authors note that while the change in the 1990s was related to the (a)-(k) student outcomes, the change is also relevant to the current student outcomes, particularly student outcome #2 (an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors) and student outcome #4 (an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts). The major change to the wood frame activity involved partnering with the Southwest Indian Foundation and the Navajo Nation to build homes, or Hogans, during FERL. The current wood frame activity students construct mobile modular housing units, complete with structural, electrical, and mechanical subsystems. The Navajo Nation provides the approved design and funding for all materials. The students learn about some of the historical aspects and cultural significance of the Hogan as they work alongside the technical experts/mentors to ensure all aspects of the homes are constructed according to the approved designs. The funding for the technical experts/mentors, which totals about $140k, is provided by the Department of the Air Force. The majority of the $140k is for three weeks of lodging for the 30-35 mentors who support FERL. The students at the United States Air Force Academy do no pay for their courses and simply live in their normal barracks rooms; therefore, there is no cost for the students. These buildings are constructed at the FERL site and then shipped to the Navajo Nation in New Mexico, where they are assembled for families in need of permanent housing. In addition to the technical skills the students obtain while working alongside trade experts throughout the build process, the project provides an excellent introduction to the cultural and humanitarian aspect of engineering. The department constructed and delivered the 50th and 51st Hogan following FERL in the summer of 2021. The department feels this project is one of the most valuable experiences for the students, and it has become the cornerstone activity within FERL.

Seniors within the program have been involved in focus groups and/or have completed individual exit surveys prior to graduation. In both cases, the students were asked to identify strengths of the program. The means of collecting the data through the years has varied between focus groups and individual surveys; therefore, some of the tabulated numerical data was simply counted as one response from a focus group, while some of data is related to individual responses. The authors did not have access to the number of students on each focus group, so the focus group data was not scaled in any way. For example if a focus group identified FERL as a strength, it received a value of one response (the same as an individual response received when not associated with a focus group). It is worth noting that Figure 1 only includes the responses with at least 10 mentions. While the data represented in Figure 1 is a mixture of responses from focus groups and individual students, it clearly shows that FERL is at the top of the list with regard to program strengths. The authors acknowledge that although the program strength data is based on open-ended response feedback, rather than a drop-down list of topics, it is likely to be biased toward the USAFA program as opposed to the validity of other programs.

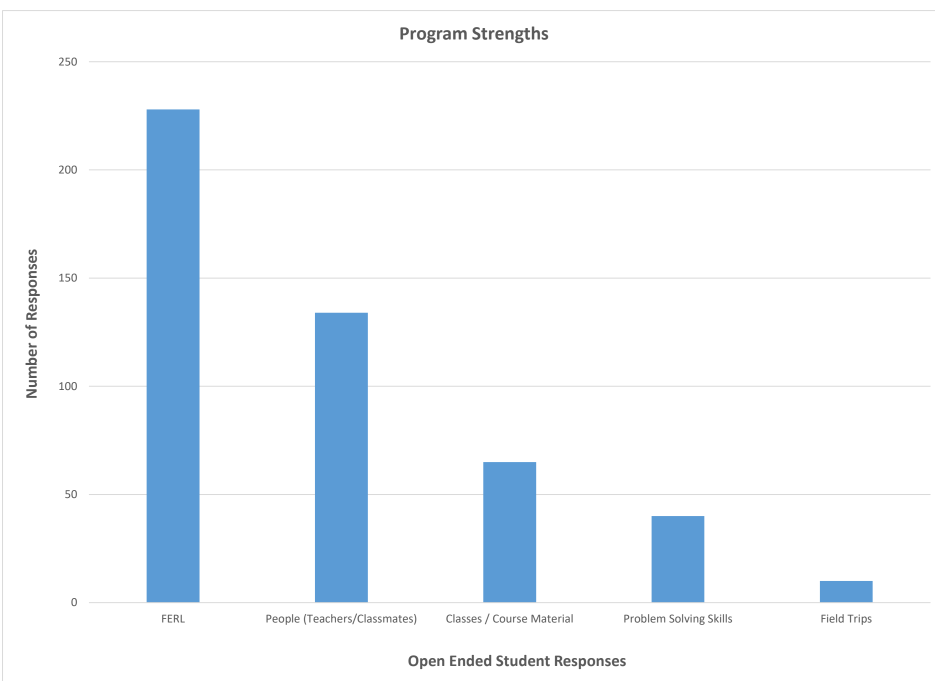

Figure 1: Program Strengths – as reported by graduating seniors in focus group or individual exit surveys

Many of the comments that students and the focus groups provided with regard to identifying FERL as a program strength were centered around the value of the hands-on experience, how it helped them in their follow on classes because they could refer back to what they had physically done during FERL, and how it inspired them to continue in the civil engineering program.

Summary:

By integrating an educational experience for students, readiness training for the reserve and active mentors, and humanitarian service for the Native American families in need—the Department of Civil & Environmental Engineering feels that FERL is a winning combination for everyone that truly embodies the educational concepts of culturally sensitive design and service learning. This faculty feel this unique program better prepares future officers and civil engineers to meet challenges both in the classroom and in practice, and that others could consider establishing a similar program.

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