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Work in Progress: Developing a Foundational Engineering Course to Improve Students' Sense of Belonging and Increase Diversity

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Abstract

This work in progress paper addresses the national imperative to promote involvement in science, technology, engineering, and mathematics (STEM) fields across all ethnicities, races, genders, and economic backgrounds. The United States Air Force Academy (USAFA) developed a Diversity, Equity, and Inclusion Strategic Plan in 2021, which includes an objective to increase the participation of students from diverse backgrounds in engineering majors. Additionally, the Accreditation Board of Engineering and Technology recently made a commitment to diversity and is considering changes to curriculum criteria which would require engineering programs to demonstrate a culture of diversity, equity, and inclusion [1]. In alignment with USAFA's strategic plan and the anticipated accreditation criteria, the authors are developing a new foundational engineering course as one element of an institution-wide effort to improve students' sense of belonging, make engineering majors more accessible to a wider audience, and ultimately increase diversity among engineering graduates.

In addition to exploring best practices from literature and other institutions, this paper describes how the authors conducted surveys and interviews from students that took a summer civil engineering field course, extracted lessons learned, and developed course content for the new foundational engineering course informed by the key findings. The interviews revealed student perceptions of how activities and interactions with instructors and peers affected their self-confidence, skill development, and sense of belonging. The first-year course under development is centered on two features: 1) a problem-based learning approach to spark interest and develop the technical skills necessary for students to be successful in an engineering major, and 2) challenging stereotypes of what types of people do engineering while stimulating a sense of belonging in engineering from students of all backgrounds.

Introduction and Purpose

It is of national interest to promote STEM fields across all ethnicities, races, and economic backgrounds [2]. Multiple research efforts have studied the causes of racial and gender disparities across undergraduate STEM disciplines. Underrepresentation of minoritized groups has been attributed to several causes, including: a gap in high school math and science performance or access to advanced placement courses, particularly among non-whites [3]; low self-efficacy and self-confidence, particularly in women [4]; and a STEM culture and climate within programs and classrooms that rouse feelings of isolation and non-belonging in undergraduates with minoritized identities [5]. This paper describes an approach to increase the diversity of students who major in engineering at USAFA. It presents the process used to develop a first-year engineering course that will be offered beginning in the Fall semester 2023.

Literature Review

Universities have undertaken a variety of approaches to address the wide range of causes for a lack of diversity in STEM majors. University or engineering school acclimation programs and

enhanced support services have been shown to increase student-to-student connections and drive positive academic outcomes across various minority groups [6]. For example, the University of Colorado at Boulder has executed a successful GoldShirt program for over a decade, aimed at providing a pathway to engineering for students who are motivated but whose high school records do not yet represent their potential. Their holistic, cohort-based approach has attracted and retained a more diverse student body to engineering [7]. Another example, the Colorado School of Mines, requires their first-year engineering students to take an introduction to engineering design course. The course grants students agency, helps develop peer relationships, involves hands-on learning, and develops technical skills required for success in more advanced courses [8].

Curriculum and teaching reform, including opportunities for hands-on undergraduate research or experiential learning, has also resulted in increased self-efficacy and academic achievement across a wide range of minority groups [9]. Since 2014, the National Science Foundation's REvolutionizing engineering and computer science Departments (RED) program has offered grants to institutions making the structural changes necessary to educate inclusive communities of engineering students prepared to solve 21st-century challenges [10]. An exemplar of this program, the Rowan University Civil and Environmental Engineering department, has changed their curriculum, pedagogy, and culture to better serve underrepresented minorities [11].

USAFA Contexts and Motivation

University Context

USAFA is a 4-year, undergraduate-only military institution. Students are required to take a rigorous course of instruction that includes academic education, military training, and athletic competition. Acceptance rates are low, around 12% [12], but graduation rates are high, approximately 80-85% [13]. Unlike many other academic institutions, incoming USAFA students are not accepted to a college or school associated with a major's program (e.g., College of Engineering). USAFA has nine institutional outcomes, and one is devoted to all graduates being able to apply the engineering method. To meet this outcome, all students take five engineering courses as a part of the general education curriculum regardless of their major. The early general education engineering courses present an opportunity to recruit undeclared students into engineering during their first year.

Field Engineering and Readiness Laboratory Context

In addition to practices from the University of Colorado at Boulder and Colorado School of Mines discussed earlier, evidence from the civil engineering majors course called the Field Engineering and Readiness Laboratory (FERL) at USAFA was used to help develop the first-year engineering course. FERL is a required civil engineering majors course taken in the summer between sophomore and junior year, prior to upper-level design courses. Academic and social integration together encourage students who might not otherwise become engineering majors to pursue and persist within these majors [14]. FERL encourages social integration since students live, eat, play, and learn in a field environment for the duration of the three-week course. Most activities have a short (one hour or less) classroom portion followed by hands-on field activities

guided by faculty, tradespeople, and upperclass students in a safe, fun environment [15]. Activities include paving an asphalt road, building a wood frame house, constructing a water purification system, operating heavy equipment, running a drill rig, welding, and building and testing concrete beams. As the civil engineering major's "cornerstone" course, graduating seniors have routinely stated that FERL was one of the main reasons they chose to pursue the civil engineering major and was also one of their best undergraduate experiences at USAFA [16]. The authors posit that aspects of FERL that motivate and prepare students to be successful in future civil engineering courses could be generalized to other disciplines and executed at USAFA as a non-disciplinary specific first-year engineering course.

Motivation for a First-Year Engineering Course

The 2021 USAFA Diversity, Equity, and Inclusion Strategic Plan stated a goal of increasing diversity in engineering. Implementing some approaches to increase diversity in engineering are challenging at a military institution given the constraints on the students and the degree programs. Creating a first-year engineering course to recruit and retain diverse talent in engineering quickly emerged as a potential solution.

A first-year engineering course is key to sparking excitement and interest in engineering during a time when students may feel particularly vulnerable as they may experience the environment shift from supportive to competitive [3]. A first-year engineering course that is interactive, appropriately challenging, and appeals to a variety of interests has been shown to be attractive to a wide range of students [17]. Whether a student goes on to declare an engineering major or not, research indicates that taking an introduction to engineering course in the first-year benefits both the student and the university as it reduces the number of students that switch majors [18].

While a first-year course is not expected to alone meet USAFA's diversity objective among engineering majors, it is one crucial piece to the puzzle (Fig 1) that includes factors within the institution's control to varying degrees. While course content is engineering and engineering-related material, the course is being designed with aspects specifically to increase interest, belonging, skills and confidence towards pursuing an engineering degree. If successful, it may result in a more diverse group of previously undeclared students choosing an engineering major.

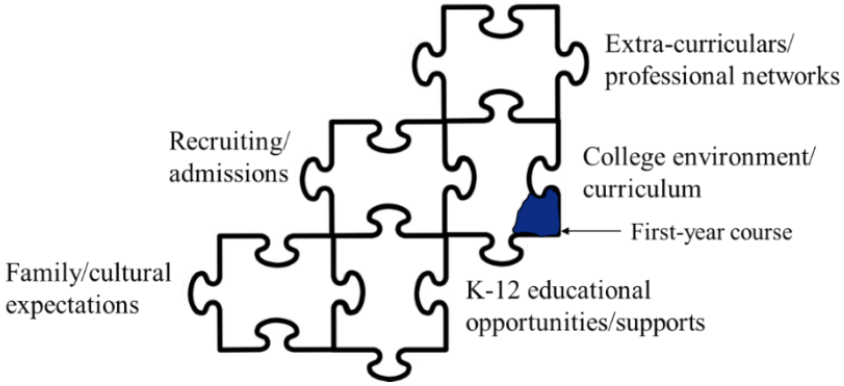

Fig 1: First-Year Engineering Course as Part of Holistic Diversity Effort at USAFA

Methods

Team Formation

Soon after USAFA published its Diversity, Equity and Inclusion Strategic Plan in 2021, engineering department chairs identified an opportunity and set the vision to develop a first-year course that could help increase not only technical skills, but also self-confidence in freshman who may be curious about engineering but would statistically otherwise not likely declare an engineering major. A planning team with representatives from the six engineering departments convened to begin brainstorming course goals and objectives. What energized this group, however, was the addition of non-engineers to the team. Members from USAFA's Office of Diversity and Inclusion as well as the student diversity and inclusion "Purple Rope" group and the faculty affinity group called "Empowering Diversity and Inclusion For Intentional Equity Development" (EDIFIED) also joined the team. A mix of engineers interested in increasing accessibility of their fields of study to more students as well as non-engineers with a sense of what types of activities, course design, and delivery methods might improve students' feeling of belonging resulted in a well-balanced team to develop USAFA's first-year engineering course. In total, about eight engineers and eight non-engineers contributed to the planning effort.

Best Practices From FERL

To investigate how aspects of FERL could be incorporated into a first-year engineering course, the authors collected data about belonging, hands-on learning, and faculty-student interactions from the FERL summer 2022 offering. A mixed-methods approach was guided and approved by an institutional review board. Quantitative survey data from 45 rising civil engineering juniors were collected anonymously and voluntarily. To complement the quantitative data and provide more insight, one team member conducted interviews with a random sample of volunteer students using a list of 18 semi-structured questions with the following themes: 1) influential experiences during FERL that had an impact on students selecting civil engineering as a career choice while in the Air Force, 2) perceptions about how their faculty and tradesperson mentors influenced their engagement, learning, personal and professional development during FERL and 3) their perceptions of the climate during FERL that contributed to their experiences of inclusion, community and sense of belonging. From the responses to the questions, insights were drawn that were deemed applicable to the development of the new first-year course. Nine students were interviewed, three of whom identified as female and five were non-white.

Findings

One question asked of students in the FERL survey was 'What was your biggest single take-away from the course?' The responses (Fig 2) yielded the following:

- Students valued the relationship and mutual respect formed with the instructors
- To a lesser degree, students valued the opportunity to get to know their peers
- Many students reported developing skills to support their success in future classes and other endeavors

During interviews, students overwhelmingly reported that working side-by-side with the tradesperson mentors and faculty while learning skills was helpful and led to mutual respect. Students appreciated being able to observe how instructors taught and led in such a way as to promote engagement, and those interactions provided a glimpse of what civil engineering may be like in practice. A strong rapport was built very quickly between most students and instructors, which resulted in more natural discussions, interactions, and learning. Research shows that speaking with ease to faculty has aided students in choosing an engineering major [19]. Similarly, the rapport with instructors is expected to reduce barriers between students and instructors in later courses and may help them persist as they continue onto future coursework.

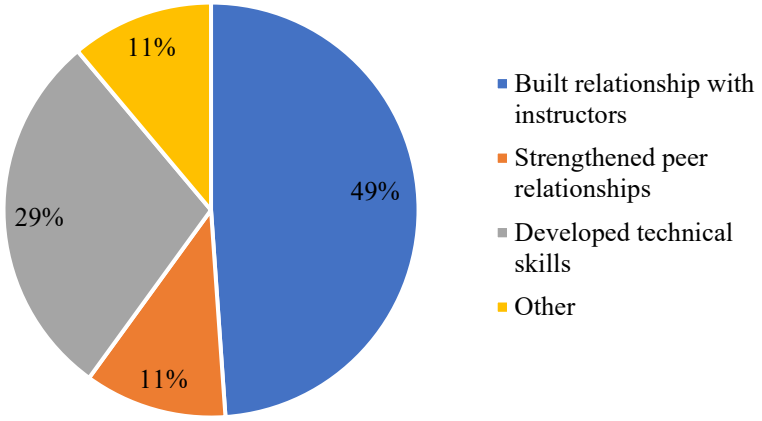

Fig 2: Biggest Single Student Take Away from FERL

In addition to a rapport with the instructors, students developed a rapport with peers going through the course as well as upperclass students helping to administer the course. Every FERL participant interviewed indicated that FERL was instrumental in providing an environment where civil engineering majors could get to know each other on a different level than what often occurs in other classes that are less hands-on or field activity-based. Deeper peer relationships support the development of social and interpersonal skills that are important during the educational experience when selecting a major [20] and later in professional careers [21]. The number of students that agreed or strongly agreed they knew their classmates well increased 17 percentage points to 67% upon completion of FERL, and the number that disagreed dropped by 12 percentage points to 7%. Due to the mandatory activities outside of class, it is expected that military institution students may know each other better than students elsewhere, however the drastic change in three weeks is noteworthy. Students indicated that the strengthened peer relationships provided the sense of being in the company of others through the progression of the major and can provide familiarity when asking for and providing help to one another in the future. Even though most of the students reported that they did not question their ability to be successful in the major, they mentioned they appreciated solidifying peer relationships.

Because FERL requires students to get outside of their comfort zone and use tools and equipment many have not used before, the course could push them away from engineering if

orchestrated poorly. For example, one student had never driven a car before; yet after some coaching, she was challenged to operate a dump truck and then a bulldozer, which she did successfully. Hands-on learning is an important part of engineering education [22]. Students interviewed reported they found great value in being able to not only see, but to actively participate in the engineering activities. The ability to meet students at their level and provide a safe environment to try something new were how students described their interactions with instructors, and ultimately the reason the hands-on learning led to an increase in skill and confidence.

Many students reported that developing tangible skills gave them confidence they could learn within the field of civil engineering and succeed going forward in the major. Some discussed being more confident in doing handywork around the house in 10 years, while others thought their experience working with rebar would help them in reinforced concrete design the following year. Regardless of the specific skill learned or how or when students envisioned applying it, walking away from FERL with a tangible skill led to an increase in confidence and commitment to the civil engineering major.

A sense of belonging and inclusion is a key factor for all students' success [23]. By attending to sense of belonging and inclusion, civil engineering students can be better prepared to succeed in their studies and beyond. While interviewees often did not have a response ready for answers to questions related to experiences of inclusion during FERL as they did for other questions related to instructors or course content, from observation the authors believe that by developing both peer and instructor relationships and providing a safe environment to develop skill and confidence, a sense of belonging in engineering was fostered.

Discussion

Armed with best practices from other institutions and local student feedback from the FERL survey data, the course was developed around the themes of sparking student curiosity towards engineering, inspiring a sense of belonging, providing technical skills, and boosting self-confidence. Lesson topics are outlined in the syllabus in Appendix A. While FERL takes place over 3-weeks, the new first-year course is a semester-long course where 40 lessons will be spread over four months. Content delivery is expected to be 30 minutes or less per lesson, while the remainder of the 53-minute lesson will be devoted to activities and group work. Students will apply and be selected to enroll in the first-year course based on a variety of considerations.

Sparking Curiosity

Topics in the first-year course are broad and diverse. During the three semester-hour course, students will work with 3D printers while learning computer aided design, hand tools while prototyping, and microcontroller chips while building electronics. Interest and curiosity in engineering begins in lesson one with a small hands-on mini-design project. This activity will draw upon one of the FERL activities, wherein students are challenged with a fictitious scenario and must purify water with only a small bin of materials to stay alive while trapped in a mine. That activity is hands-on, low-stakes, and is completed prior to learning about the more advanced water chemistry topics.

Beyond lesson one, the first-year course will be centered on an engineering design problem within a problem-based learning (PBL) framework and a semester-long project. The PBL pedagogical approach, which offers students agency to solve open-ended, ill-structured problems, has been shown to develop critical thinking and problem-solving skills [24]. The design output from the semester-long project will be the main, tangible deliverable the students will have from the course. This approach will expose students to a variety of engineering disciplines, offering tools that students will need if they declare an engineering major.

Sense of Belonging

When students feel a sense of belonging, at a course-level, they are more likely to be academically motivated [25]. For students to belong in the classroom and among other engineering majors, another important attribute of the new first-year course is how it helps students to see themselves as an engineer. Assignments will highlight the engineer behind the engineering, revealing women, people of color, and those with various gender identities as successful engineers. The assignments are modeled after the successful "Scientist Spotlight" program which has helped boost student confidence, demonstrate inclusion, and foster a growth mindset [26]. By adapting the program to engineering, it is expected to challenge stereotypes of what types of people do engineering and allow students to feel that no matter who they are, they are not alone, and they belong in engineering if that is what they choose to study. Additionally, there will be at least two touchpoints during the semester where freshmen and upperclass students see each other's work. For example, at lesson 15, freshmen will be invited to observe a senior capstone project design review of an engineering discipline of their choice. The interaction with seniors, only three years removed from their freshman year, are expected to be another means to nurture belonging in those taking the first-year course.

Helping students connect their personal identities to their engineering identity is one way to increase persistence [27]. There are several opportunities within the course to highlight the benefit of teamwork, practice constructive teamwork, and realize all members bring value and perspective. As students benefitted from getting to know their peers and upperclass civil engineering majors during FERL, the authors envision an off-site experience for the students to bond outside the classroom and complete a local service project in the community or conduct STEM outreach to local high schoolers. The first-year course will contain students from diverse backgrounds. Classroom diversity is expected to facilitate belonging and has been shown elsewhere to improve grades as well as the propensity to pursue engineering [28].

Skills Development

Despite the first-year course having many activities intended to be fun for students such as prototyping in the laboratory, there also needs to be an appropriate amount of rigor in the course content to help close the gap in preparation for subsequent undergraduate-level STEM courses. A blend of fun and technical content can lead to increased student engagement [29]. The course will develop critical thinking and problem-solving skills and tools that will benefit students in a wide range of general education courses. At USAFA, along with humanities, social sciences, and basic sciences, general education requirements include 15 semester hours of engineering courses. Skills such as literature review, project management, and technical communication, which

students will practice in this first-year course, are expected to be useful in several future courses and in their careers.

Boosting Self-Confidence

Engineering education, if it emphasizes not only skill acquisition, but also appeals to the social sense of students, helps students connect more fully with the discipline [30]. This connection will help them navigate some of the rigors of the discipline and inspire confidence. Confidence both requires and fosters qualities such as grit, persistence, and motivation. FERL students reported that positive, affirming interactions with instructors during class and when receiving help with the activities were key to ensuring the learning process improved and not detracted from self-confidence. FERL is designed to get students outside their comfort zone, but also to provide a safe space to try new things, make mistakes, receive help, and try again. The authors believe that equally important to the first-year course content is how the content is delivered. Subtle, affirming verbal and non-verbal things instructors can do to build student confidence include listening, encouraging, and motivating. Whereas actions like lack of eye-contact, non-affirming comments, or appearing preoccupied can have the opposite effect [31]. Deliberately chosen instructors who utilize teaching practices that encourage confidence, skill development and belonging will teach this freshmen-level course. Pre-class training and small group discussions will be required for new instructors of this course.

Conclusions and Key Take-Aways

Applying best practices from other institutions and local student feedback, the USAFA planning team developed a first-year engineering course to appeal to and support students from a wide range of backgrounds and increase the diversity of students across engineering majors. In addition to best practices from other schools, the authors have found it worthwhile to take lessons learned and student feedback from a junior-level course within the institution in the planning of the broader first-year course aimed at a less experienced audience. Relationships with instructors, bonding among peers and skill development were the most positive attributes of the junior-level course as reported by students. Authors have found that curiosity, belonging, skills and confidence are the foundational attributes upon which to build the first-year course. The first-year course will be taught through a problem-based learning approach by instructors deliberately trained and selected for this role.

Assembling a team of both engineers and non-engineers devoted to increasing diversity was found to be an excellent means to develop the course. Incorporating affinity groups, both faculty and students, provided helpful perspectives. The planning process required faculty time and effort, but all involved took on the role with passion and purpose. The first offering of the course will be the Fall semester 2023 with one section of about 20 students; therefore, results and student feedback are not yet available. Assessment will consider students' level of growth mindset towards the types of people that do engineering, self-confidence in their own ability to successfully pursue an engineering degree, and how many declare and persist in an engineering major. Full development of assessment methods, both qualitative and quantitative, is currently underway.

Disclaimer

The views expressed in this article are those of the authors and do not necessarily reflect the official policy or position of the United States Air Force Academy, the Air Force, the Department of Defense, or the U.S. Government.

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Appendix A: First-Year Engineering Course Syllabus

Lesson	Lesson Activities	Lesson	Lesson Activities
1	Mini-design challenge	21	Electronic prototyping
2	Problems and opportunities	22	Electronic prototyping
3	Engineering problem solving process	23	Work session
4	Teamwork	24	Requirements and specifications
5	Idea generation	25	Decision making
6	Empathy and user-centered design	26	Feedback and peer evaluations
7	Problem identification and validation	27	Systems and subsystems
8	Stakeholder engagement	28	Design Review
9	Literature review	29	Testing and Analysis
10	Idea generation	30	Technical communication
11	3D visualization	31	Work session
12	3D visualization	32	Value proposition
13	Computer aided design	33	Risk mitigation
14	Computer aided design	34	Cost estimation
15	Senior capstone observation	35	Work session
16	Soft prototyping	36	Proof of concept construction
17	Soft prototyping	37	Work session
18	Hard prototyping	38	Work session
19	Hard prototyping	39	Work session
20	Concept Review	40	Final Presentations