IUSE/PFE: RED – Implementing and Refining Learning Environments to Develop Holistic Engineers with Entrepreneurial Mindset

Dr. Donald R. Webster, Georgia Institute of Technology

Donald Webster, Ph.D., P.E. is the Karen & John Huff School Chair and Professor in the School of Civil & Environmental Engineering (CEE) at the Georgia Institute of Technology in Atlanta, Georgia. Dr. Webster earned a B.S. from the University of California, Davis (1989), and M.S. (1991) and Ph.D. (1994) degrees from the University of California, Berkeley. He joined the Georgia Tech faculty in September 1997 after completing a postdoctoral research appointment at Stanford University and holding a non-tenure-track faculty position at the University of Minnesota. Dr. Webster's research expertise lies in environmental fluid mechanics focused on the influence of fluid motion and turbulence on biological systems. His contributions have been in three arenas: 1) illuminating the fluid mechanics processes related to sensory biology and biomechanics; 2) developing advanced experimental techniques and facilities; and 3) translating research results into bio-inspired design. In recognition of these contributions, Dr. Webster is a Sustaining Fellow of the Association for the Sciences of Limnology and Oceanography (ASLO) and has won numerous awards including the Felton Jenkins, Jr. Hall of Fame Faculty Award, Class of 1934 Outstanding Innovative Use of Education Technology Award, the Eichholz Faculty Teaching Award, and the British Petroleum Junior Faculty Teaching Excellence Award.

Dr. Adjo A Amekudzi-Kennedy, Georgia Institute of Technology

Professor Adjo Amekudzi-Kennedyâ€™s research, teaching and professional activities focus on civil infrastructure decision making to promote sustainable development. She studies complex real-world systems and develops infrastructure decision support system

Dr. Kevin Haas, Georgia Institute of Technology

Associate Chair of Undergraduate Programs, School of Civil and Environmental Engineering

Dr. Kate Williams, Georgia Institute of Technology

Kate Williams is a psychologist and faculty developer in the Center for Teaching and Learning at Georgia Tech who partners with faculty and academic leaders to design and assess curricular transformation that supports achievement of the Institute's mission to prepare students who advance technology and improve the human condition.

IUSE/PFE: RED – Implementing and Refining Learning Environments to Develop Holistic Engineers with Entrepreneurial Mindset

Introduction

This paper summarizes the design, implementation, and assessment of a multi-year professional formation experience (PFE) in the undergraduate program of a research-intensive School of Civil and Environmental Engineering (CEE). Motivated by the historical loss of CEE students to other majors, this PFE-initiative was implemented to engage students early in the major in order to enhance undergraduate students' sense of belonging to the profession, and to augment their engineering efficacy and computational and professional skills. A carefully-curated faculty development series prepared the project team to design and pilot a vertically-integrated spine of courses required for all CEE students. These courses cultivate problem identification and solving around the global grand challenges; computational, communication, teaming, and reflective learning skills; and stakeholder awareness and engagement at increasing levels of maturity. The School subsequently adopted the primary goals of the PFE-initiative as part of its five-year strategic plan and worked to scale up and implement the piloted courses for all CEE students. The School has since initiated a collaboration with the Center of Teaching and Learning to develop an approach and plan to assess program outcomes for monitoring and refinement. This paper describes the motivation for the PFE-initiative, explains its key design elements and rationale, discusses critical factors for implementing and sustaining the initiative, and introduces a plan for assessing initiative outcomes. The scalable framework may be useful to other engineering departments looking to boost retention, the undergraduate experience, and the preparedness of the engineering graduate. This initiative was supported by a grant from the National Science Foundation (Revolutionizing Engineering Departments Program) and an entrepreneurial mindset development grant from the Kern Entrepreneurial Engineering Network.

Motivation for the Professional Formation Experience (PFE) Initiative

In 2018, the School of Civil and Environmental Engineering (CEE) at the Georgia Institute of Technology (Georgia Tech) embarked on a curriculum innovation initiative to augment undergraduate student retention. Starting with a baseline retention rate of 50%, the PFE-initiative aimed to enhance student sense of belonging to the profession and major, improve student efficacy in engineering, and strengthen professional identity [1]. A similar trend existed nationally in engineering programs with 40-60% of engineering students dropping out or changing major [2].

PFE-Initiative Design Rationale and Design

Internal and external reports had highlighted the importance of developing holistic engineers, that is – engineers who can integrate cognitive, affective and interpersonal skills and apply them in effectively in problem-solving and design [3,4,5]. Entrepreneurial mindset (EM) development in the context of engineering supports this: engineering students with an entrepreneurial mindset are curious, make connections to the broader environment, and habitually seek opportunities to create value [6,7]. The PFE-initiative design approach was therefore to develop and implement a

cohort-based learning environment that cultivates engineering and professional skills, and develops professional identity at increasing levels of maturity. Carefully-curated faculty development efforts were essential to enable the faculty to deliver on these PFE-initiative objectives. A series of workshops on problem-based learning (PBL), entrepreneurially-minded learning (EML), value sensitive design (VSD), and story-driven learning (SDL) expanded faculty pedagogy portfolios, which were then applied in creating new courses and upgrading existing ones. In 2024, the School's faculty approved a vertically-integrated spine of courses (Figure 1), central in the curriculum and aimed at engaging all civil engineering and environmental engineering majors early and keeping them engaged throughout the program. The courses cover CEE content and are linked by specific skills and mindsets that are developed with increasing nuance and maturity as the students advance through the program [6].

Critical Factors for PFE-Initiative Implementation and Sustainability

As much a cultural change as a curriculum change, the PFE-initiative included several critical factors to support lasting change [8,9]. A School-wide climate study conducted to assess the sense of belonging, engagement, and perception of support in the undergraduate students, graduate students, staff members, and faculty, served as an important baseline and point-of-departure for the intervention effort, enabling collective reflection on what was working well and where change was needed. Subsequent interim updates of the climate study were essential for benchmarking progress in the initiative. Developing a shared vision was critical at the beginning of the process and on an ongoing basis to sustain the PFE-initiative, particularly when key core group members moved to new positions elsewhere. Engagement was an important tool for informing the School's stakeholders (students, faculty, staff, and alumni) as well as obtaining their input to guide the PFE-initiative. Engagement was also critical for managing areas of tension, for sharing early and continuing successes, and for building consensus around key change initiatives in the intervention. Engaging smaller groups in advance of a full faculty discussion enabled initiative leaders to understand better the priorities and constraints of groups within the School and to reflect these in the curriculum change proposals subsequently brought to the full faculty for review and approval. Institutionalizing the PFE-initiative objectives in the School's strategic plan was an effective approach by moving the objectives from incidental to a central position of importance. Strategic planning served as a unifying tool to advance and sustain the PFE-initiative objectives well beyond the end of the formal intervention. Provision of resources to advance the initiative took the form of hiring a learning scientist to coordinate the necessary faculty development in order to equip faculty to implement the PFE-initiative objectives, and making resources available to faculty to support changes in their courses aligned

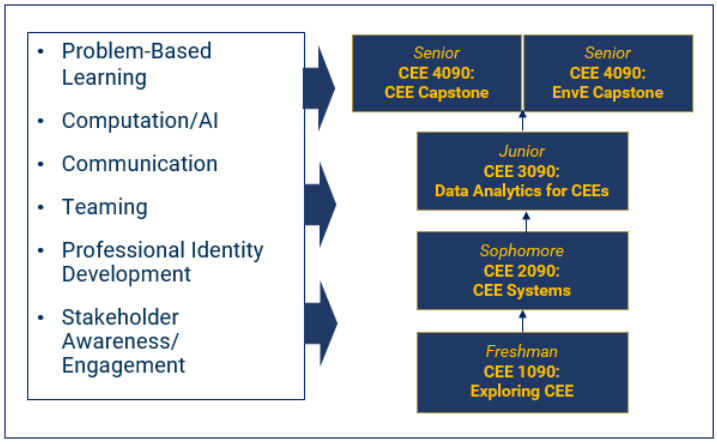

Figure 1: Cohort-Based Vertically Integrated Learning

with the objectives. An award for applying best practices in engineering education (aligned with PFE values and supported by the requisite faculty development) has created incentives to sustain the changes introduced by the intervention. And finally, mentoring from peer programs, the REDPAR community of practice, and the Kern Entrepreneurial Engineering Network, was essential in guiding the PFE-initiative team to evidence-based effective practices, helping the team avoid pitfalls, and supporting a more efficient and effective change process.

Initial PFE-Initiative Impacts

Retention was a main motivation for pursuing the PFE-initiative. In the years following the inception of the initiative, there has been improvement in retention of the students taking the first-year course: Exploring Civil and Environmental Engineering (CEE 1090), compared with the baseline of 50% of declared CEE students leaving for other majors. Table 1 shows that the retention of CEE majors has consistently increased since the initiative began.

Table 1: Retention of Civil Engineering and Environmental Engineering Majors following Enrollment in the First-Year Course

Year	Semester(s)	Class Size	Retention
2019	Fall	24	75%
2020	Fall	48	73%
2021	Fall	64	66%
2022	Fall	60	80%
2023	Fall	59	93%
2024	Fall	133	83%
2025	Spring	50	96%

Other evidence of impact, from direct and anecdotal evidence, includes improved understanding of engineering concepts [10], augmented professional identity development, and improved team skills (Table 2).

PFE-Initiative Assessment and Program Refinement

To assess how the changes are delivering the intended outcomes and to further refine the learning environments, CEE began a collaboration with the Center of Teaching and Learning (CTL) at Georgia Tech to design and implement an assessment plan, following the curriculum reform. The CTL faculty member engaged CEE leaders in a curriculum mapping exercise [11] to visually represent the alignment of learning outcomes, instructional approaches, and assessment of learning across courses. Students are expected to achieve increasing mastery of the following nine cognitive and affective learning outcomes across the four-course sequence for cohort-based, vertically-integrated learning: (1) problem definition and problem solving, (2) data analysis, (3) inquiry/research, (4) communication, (5) teaming, (6) reflective learning, (7) professional identity development, (8) stakeholder awareness/engagement, and (9) entrepreneurial mindset. A focal assignment was identified in each course and an appropriate target performance level was set for that assignment based on the course's position within the spine curriculum. As this work progresses, student work will be evaluated using relevant VALUE rubrics [12], revised slightly to ensure alignment with the learning outcomes. Data from this assessment effort will be used to evaluate the success of the curricular intervention and to generate formative feedback to allow for continuous improvement.

Table 2: Student Reports on the Impact of the Spine-Course Sequence

CEE 1090: Exploring Civil and Environmental Engineering | Excerpts from Final Reflection "This course has expanded my view of what CEE actually is. Before taking this class I was struggling to describe my major to my parents. After, I can't stop talking about what I am excited about because of this class." "This class has made me discover where I want to go with this major and has me excited to start taking more courses specific to the major." "Before we started this section, I was really having issues with imposter syndrome, not just at this school, but within my major." "I can look back on this assignment and remind myself that there are things in this major that excite me, and it is worth the long haul to be able to make a positive impact on the planet."
CEE 2090: Civil and Environmental Engineering Systems | Unsolicited Feedback "I just finished a scholarship essay about my interest in civil and environmental engineering, and I wanted to share it with you. I really enjoyed the first module, and I found that I drew from the things I learned in your class quite a bit for this essay, including some of the content from Dr. Clough and Dr. Bonaparte's lectures. I have found that I am able to better articulate what I want to do after just a few weeks in your class, and am very grateful for that."
CEE 3090: Data Analytics in Civil and Environmental Engineering | Course Feedback "I am graduating in a few days. I see myself applying these concepts heavily in my career. I am very excited to see what forms of data I will have access to so I can try to apply these concepts. I am going into water resource engineering. I can see myself directly applying these concepts to water level data to build predictive models. I will also be working in water treatment. I can see myself applying this stuff to contaminant concentration modeling." "The Python syntax and coding functions and packages that I learned in this course will be helpful for me in the future. Additionally, the concepts of how data analytics models are developed are important to know when applying ideas to predict future information. I am now interested in data analytics as a potential career opportunity, so I ideally see myself applying lessons learned from this course directly to work in the future." "I can see myself applying these machine learning techniques to many other courses and internships. Specifically, I was working on a capstone project to assist the Braves stadium in reaching zero waste, which requires a thorough prediction of the waste generated from each game. Since there are many features that impact the overall waste production, it's difficult for the stadium to accurately predict how many waste hauls will be required after each homestand. I could apply the skills I learned in this class to anticipate the amount of waste generated from a game based on the ticket sales, time of day, and day of the week!"

Summary and Conclusion

The School of Civil and Environmental Engineering at Georgia Tech pursued an initiative focused on a professional formation experience to improve undergraduate retention through early and continuing engagement to improve sense of belonging, augment professional identity and enhance student efficacy in engineering. This paper presents the key features of the program design, effective practices for managing the change initiative, and initial evidence of successes as a resource that other engineering departments may adopt, scale, and tailor to enhance the undergraduate experience, boost retention, and graduate more holistic engineers with entrepreneurial mindset equipped to create augmented value in industry.

Acknowledgement

Funding support is gratefully acknowledged from the National Science Foundation via grant IUSE-2022298.

References

[1] E. Zerbe, A.A. Amekudzi-Kennedy, K. Haas, E. Grubert, S.E. Burns, I. Tien, K. Watkins, J.H. Koon, R.S. Simon, J.E. Taylor, L.G. Rosenstein, and D. Webster, "Early engagement and vertically-integrated learning: Developing whole-person and entrepreneurially-minded engineers," American Society for Engineering Education Annual Conference, 2022. https://peer.asee.org/41453

[2] N. Desai and G. Stefanek, "A literature review of the different approaches that have been implemented to increase retention in engineering programs across the United States," ASEE Zone II Conference, 2017.

[3] Georgia Institute of Technology, "Deliberate innovation, lifetime education: Final report of the Commission on Creating the Next in Education," 2018. https://provost.gatech.edu/commission-creating-next-education-cne

[4] K. D. Hall, D.G. Linzell, B.S. Minsker, J.F. Hajjar, and C.M. Saviz, "Civil Engineering Education Summit: Mapping the Future of Civil Engineering Education," 2019.

[5] National Association of Colleges and Employers, "Job Outlook 2023," 2022.

[6] E. Zerbe, A.A. Amekudzi-Kennedy, K. Haas, and D. Webster, "Designing learning environments for knowledge, skills, and mindset development," American Society for Engineering Education Annual Conference, 2023. https://peer.asee.org/42690

[7] Engineering Unleashed, "Entrepreneurial Mindset", https://engineeringunleashed.com/mindset, 2022.

[8] A. Amekudzi-Kennedy, D. Webster, E. Zerbe, S. E. Burns, M. Hunter, J. Melkers, and T. Blum, "Effective practices and lessons learned in managing and sustaining curriculum and cultural change at CEEatGT," American Society for Engineering Education Annual Conference, 2025. https://peer.asee.org/56319.

[9] E. Andrijcic, S. Mohan, E. Litzler, R.J. Han, A. Amekudzi-Kennedy, D. Webster, K. Haas and C. Woolard, "Fixing the potholes on the road to academic success: A curriculum for engineering educators to create and sustain meaningful change," *Educ. Sci.*, vol. 15(11), num. 1509, 2025. https://doi.org/10.3390/educsci15111509

[10] K. Haas, A.C. Muscalus, E. Zerbe, and R.B. Simon, "Incorporating teamwork elements into a course to improve learning outcomes," American Society for Engineering Education Annual Conference, 2023. https://peer.asee.org/43646

[11] P. Dyjur and N. Kenny, "Analyzing curriculum map data: Enhancing student learning through curriculum redesign," Conference on Postsecondary Learning and Teaching, 2015. http://hdl.handle.net/1880/50575

[12] Association of American Colleges and Universities, "Inquiry and analysis VALUE rubric," 2009. https://www.aacu.org/initiatives/value-initiative/value-rubrics/value-rubrics-inquiry-and-analysis