Engineering Gateway Course Redesign for Equity through Critical-Paths

Dr. Praveen Meduri, California State University, Sacramento

Dr. Praveen Meduri is an Assistant Professor of Electrical and Electronic Engineering at Sacramento State University. He is also a Technical Liaison to Cadence Design Systems. He received his PhD from Old Dominion University, VA, M.S. from Southern Illinois University, Carbondale and bachelors from JNT University, India.

His research interests include Embedded Systems, Smart Cities, VLSI Design and Engineering Epistemologies.

Mohammed Eltayeb, California State University, Sacramento
Dr. Milica Markovic, California State University, Sacramento

Milica Markovic is a Professor of RF Engineering at California State University, Sacramento. She graduated from the University of Belgrade, Serbia, and received her Ph.D. in Electrical Engineering from the University of Colorado, Boulder. Her research interests are high-frequency circuits and engineering education.

WIP: Engineering Gateway Course Redesign for Equity through Critical Paths

Abstract

In this paper, we describe an ongoing project involving a comprehensive redesign of six Electrical and Electronic Engineering (EEE) undergraduate courses at Sacramento State to reduce equity gaps by incorporating culturally responsive pedagogies, inclusivity, and equity best practices. The goal of this project is to engage engineering students in active-learning experiences that are transformative, evidence-based, and aimed at closing equity gaps, improving persistence, and increasing graduation rates for all students.

The construct of course redesign along the critical path as an effective means to reduce barriers to student progress to a degree in STEM is a novel concept. We anticipate that this project will demonstrate that the advantages of the critical-path redesign are greater than the parts of individual gateway course redesign in engineering.

This project is jointly sponsored by the College of Engineering and Computer Science, the Office of Undergraduate Studies at Sacramento State, and by NSF grant (DUE # 2235774).

Introduction

Engineering curricula characteristically have long and highly regimented chains of pre-requisite courses called ***'critical paths'***, that span the entire curriculum from students' freshmen year to senior-year capstone projects. Critical-path courses can create significant obstacles to graduation as a single DFW (grade of D, F, or withdrawal) grade in any course can impede a student's ability to graduate on time. Reducing course fail rates along the critical path significantly reduces the students' time to degree. Furthermore, research shows that students exposed to engineering design [1] and research experiences [2] have a greater sense of belonging to discipline, self-efficacy, and career readiness; particularly for under-represented minority (URM) students [3]. However, such active-learning experiences are usually offered late in their engineering degree (e.g., senior-capstone projects) rather than early and often throughout the curriculum. Most redesign efforts to address this issue typically focus on single, or multiple but disjointed gateway courses [4]. An example of a critical path in the Electrical and Electronic Engineering (EEE) department at Sacramento State is shown in Figure 1.

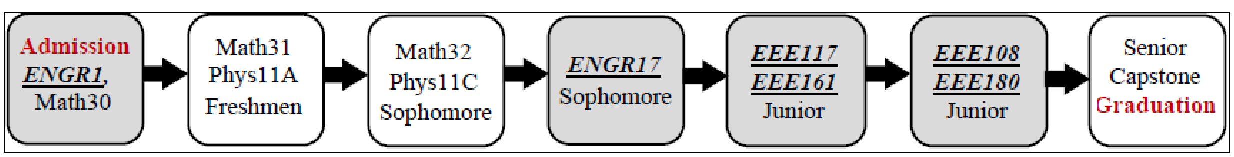

Figure-1: Example curriculum path in the EEE major, showing long engineering pre-requisite chains called critical-paths. Courses shown in Bold, shaded, are redesigned as a part of the proposed project.

Opportunity Gaps and DFW Disparities

Critical-path courses typically have very high fail rates, contributing to significantly high attrition rates in Science, Engineering, Technology, Mathematics (STEM) disciplines. For various reasons, Hispanic students and students of color in STEM have higher DFW and college drop-out rates than their white peers [5]. These disparities are representative of the nationwide trends [5]. DFW disparity for students of color conflicts with the nation's urgent need for a diverse and well-prepared STEM workforce.

Table 1 shows the average GPA gaps of selected critical path courses at Sacramento State between Fall 2012 and Fall 2022. The average GPA gaps are shown for first-generation (First Gen), Under-Represented Minorities (URM), Pell Grant eligible, and Female students, compared to their counterparts. A positive GPA gap indicates that the average course grade received by the demographic over eleven years is lower than the comparison group. As seen in Table-1, First Gen, URM, and Pell student groups consistently receive lower grades. In addition to GPA gaps, similar DFW disparities in these courses are also noticed.

Table-1. Selected critical-paths courses and their average GPA gaps (Fall 2011- Fall 2022).

Course proposed for redesign	First Gen vs Non First Gen	URM vs Non-URM*	Pell vs Non-Pell	Female vs Male
ENGR1 Introduction to Engineering	N/A	N/A	N/A	N/A
ENGR17 Introductory Circuit Analysis	0.22	0.17	0.17	-0.09
EEE117 Network Analysis	0.1	0.15	0.05	0.08
EEE108 Electronics I	0.02	0.42	0.05	-0.01
EEE161 Applied Electromagnetics	0	0.4	0.14	0
EEE180 Signals & Systems	0.05	0.33	0.1	0.07
URM and First Generation enrollment ~30%, Female enrollment ~15%, Pell enrollment ~50% of the total enrollment. Based on a total enrollment of about 1500 students per class.				
*African American average GPA gap is significantly higher than URM, typically 0.3-0.85, and enrollment is about 5% of the total. A 0.4 gap in GPA separates 'B+' and 'A-' grades, for example.				
Data provided by the California State University Student Success Dashboard [30]				

To overcome the GPA gap and the DFW disparities, we plan to redesign six critical-path, large enrollment courses ENGR1 Introduction to Engineering, ENGR17 Introductory Circuit Analysis, EEE117 Network Analysis, EEE108 Electronics I, EEE161 Applied Electromagnetics, and EEE180 Signals & Systems, based on active-learning, culturally responsive strategies, and best practices for equity. The active-learning strategies include Project-Based Learning (PBL) and Course-Based Undergraduate Research Experiences (CURE) that incorporate culturally responsive projects. The equity principles incorporated include best practices from the Association of College and University Educators (ACUE) and the Equity Toolkit [6].

The rationale for choosing the six courses is that by focusing the redesign efforts on a sequence of critical-path courses, the concerted redesign will positively impact students' graduation rates by reducing DFW rates and GPA gaps. Furthermore, these courses are typically mandatory in any Computer and Electrical Engineering Department. Their redesign can significantly impact student success and offer insights for broader equity-focused engineering course redesigns. We hope redesigning these six courses will result in a department-wide reform towards equity and reduce DFW rates across all demographics by 30%. Institutional data will be used to measure this improvement by comparing fail rates in all critical-path courses for the pre and post-implementation cohorts.

Guiding Philosophy

The guiding philosophy of this project can be summarized as:

- Engage engineering students in transformative active-learning experiences.
- Use evidence-based practices to close equity gaps and DFW rates, and therefore increase persistence and graduation rates of all students;
- Analyze and evaluate the effects of course redesign through institutional and course-level data.

Theoretical and Empirical Base

Active Learning as The Equalizing Educational Experience

Categorized under inquiry-based learning in the theoretical framework of 'How People Learn' [7], a significant body of research demonstrates that active learning is an effective intervention for developing STEM core competencies [8]-[11]. Active learning activities, including Project Based Learning (PBL) and Course based Undergrad Research Experiences (CUREs), engage students in open-ended, real-world design projects addressed by scientists and engineers in the workplace [12]. The effectiveness of PBL and CUREs as high-impact practices in closing equity gaps among URM students is well established [13]. To enhance students' conceptual understanding, the six courses chosen for redesign will use contextual PBL and CURE projects with concrete everyday examples and application-oriented discipline-specific projects [15]. As shown in [14], the general idea is to start from the most concrete, real-world examples and work toward more abstract concepts.

By introducing PBL into the ENGR1 Introduction to Engineering course, freshmen's first-year experience (FYE) is expected to be significantly enhanced. High-quality first-year experience is a high-impact practice that effectively reduces student attrition rates, particularly among underserved demographics like URM students [5]. Based on the well-established theoretical framework of 'Tinto's Theory of College Student Withdrawal' [16], the ENGR1 course redesign will improve the social and academic integration of freshmen students and student persistence, belonging, and self-efficacy. In addition to ENGR1, PBL will be employed in ENGR17, EEE108, and EEE161 courses. The EEE117 and EEE180 courses will employ CURE-based active-learning projects.

Culturally Responsive and Sustaining Pedagogy

Culturally Responsive Pedagogy (CRP) promotes diversity and inclusivity in STEM education and calls for transforming the curriculum, student-teacher relationships, classroom climate, and instructional and evaluation strategies [16]. In [17], Herrera et al. argued that Hispanic and other URM students feel a lower sense of belonging to STEM disciplines due to conflicting cultural and STEM identities and values. Furthermore, Latinx students often pursue STEM majors motivated by altruistic values like social justice, advancing humanity, and giving back to their community. CRPs break down the false dichotomy of STEM problems as strictly "technical" or "social" and play a key role in connecting science with real-world and community problems [18], [19]. This enables students to develop their science and cultural identities without conflicts and improves the students' self-efficacy, belonging, and identity to STEM [17], [18], [20], [21].

Culturally Sustaining Pedagogy (CSP) involves students selecting and working on projects relevant to their native social and cultural backgrounds. This pedagogy can help promote a sense of belonging and community in the classroom by acknowledging and valuing all students' diverse cultural backgrounds and experiences [18]. This is particularly important for traditionally marginalized students who may feel excluded from mainstream engineering culture.

Course Transformation for Equity and Inclusivity

Implicit biases that faculty bring to the classroom may be one of the factors that perpetuate STEM inequities and marginalize certain groups of students in engineering [18]. CSPs can help mitigate the effects of implicit biases and create a more equitable learning environment for all students by valuing and acknowledging all students' diverse cultural backgrounds and experiences [18]. Additionally, asset-based pedagogy that values diversity and inclusivity is critical for reducing STEM inequities [22]. The Association of College and University Educators offers a list of inclusive practices that can be readily incorporated into any classroom [6].

Micro-Lectures and Unified Course Content

An effective type of resource for online and in-person learning is video content. Online micro-lectures provide greater flexibility and access to education [23]. Based on an analysis of 6.9 million video views (from numerous massive open online courses), 6–9-minute micro-lectures elicit maximum student engagement with content, improve student learning and reduce equity gaps [12], [23] - [25]. The lecture length of 6 – 9 minutes maximizes student learning [23], [24]. Through an internal grant, two courses, ENGR 17 and ENGR 1, are redesigned to incorporate micro-lectures, inclusive practices, anonymous grading-based assessments [26], and contextualized examples [18]. We expect that these strategies will create an inclusive classroom environment that will reduce equity gaps, stereotype threat [26], implicit bias [27], and microaggressions [28], [29]. The new, unified, and inclusive courseware developed in this project will supplement in-class instruction and will be shared widely with all instructors in different sections.

Project Significance and Scalability

The results of this ongoing project will be of interest to a wide range of audiences in STEM fields as the project addresses equity gaps in engineering courses. The project is grounded in theoretical research and empirical evidence, shown to reduce widespread equity gaps in STEM disciplines. Thus, the interventions can be extended to various contexts, including the college, campus, and university system levels for STEM instruction and redesign centered around the novel construct of redesigning a sequence of gateway courses along the critical path.

Design and Implement ALEs in Six Existing Required Courses

The proposed active learning models (PBL and CURE) can be easily scaled up to include all relevant engineering courses in the College of Engineering and Computer Science and colleges that offer engineering and STEM major degrees. The efficacy of PBL and CUREs in student retention and in reducing equity gaps has been well established in engineering and other disciplines. In this learning model, students will engage in the engineering design cycle from conception, specification, design, modeling, prototype, testing, validation, redesign, and documentation through real-world projects with cultural significance. Furthermore, the project culminates with a team presentation, a written report, and a peer-review component. Such inquiry-based, collaborative learning experiences, rooted in constructivist learning principles, have improved retention, academic performance, self-efficacy, and sense of belonging to discipline across students of different demographics [2], [18].

Instructional Scaffolding

The efficacy of active learning is wider than engineering since the underlying principles of scaffolded, active-learning, student-centered pedagogy can be applied to reduce equity gaps in all disciplines by carefully choosing discipline-specific, collaborative projects.

Project Activities

Active-Learning Activities: During Fall 2023, the four PBL mini-projects will be developed and integrated into ENGR1 and ENGR17 to pilot test the project. In each course, students will complete two four-week mini-projects and participate in a culminating poster presentation session showcasing their work at the end of the semester. Finally, the effectiveness of the pilot PBL will be assessed by administering a formative student survey and an evaluation of DFW rates and equity gaps based on institutional data.

Afterward, based on this pilot study, faculty will modify the course activities for revised implementation beginning in Spring 2024 by adding culturally responsive, semester-long projects in addition to the four mini-projects developed earlier. These redesigned courses will be fully implemented and offered in Fall 2024. During this period, a team of graduate and/or undergraduate students with experience from the pilot study will be employed as teaching assistants to assist the faculty with implementing and assessing PBL and CURE in the EEE117, EEE 161, EEE 108, and EEE 180 courses.

Course Design for Inclusive Pedagogy Based on ACUE: In Fall 2023, faculty will redesign the three courses by creating new, inclusive syllabi. In addition, faculty will use the Backwards Design methodology to align student learning outcomes with instructional materials, technology, assessments, and activities. Open Courseware and Affordable Learning Solutions (AL$) will be integrated into the courses, and the course material will be updated to be accessible to all students. The creation of anonymous, auto-graded assignments will also begin in Fall 2023 to eliminate implicit bias by the instructor.

In selecting textbooks, references and guest lectures, and course material, a conscious effort will be made to showcase role models from diverse backgrounds and highly successful URM role-model engineers. A robust library of contextualized examples will also be curated for each redesigned course to explain the concepts through real-world similes and examples. Student activities will be intentionally created to enhance the sense of belonging and inclusivity and engage students in active learning. The redesigned courses will employ ACUE’s best practices for inclusivity. A formative assessment of redesigned ENGR 1 and ENGR 17 courses will be performed in Spring 2024 based on a checklist of 10 inclusive teaching practices by ACUE’s toolkit [6].

EEE 117, EEE 108, EEE 161, and EEE 180 will be redesigned and revised in an iterative process that spans from Fall 2023 to Spring 2026.

Conclusion

University is a microcosm of the increasingly pluralistic society that we live in. The disparity and opportunity gap amongst students of various demographic, cultural, and racial identities remain unacceptably high in Engineering. This paper describes a work in progress jointly sponsored by Sacramento State and NSF. The project aims to establish a novel construct of critical-path redesign relevant to STEM fields. Through judicious course redesigns along several critical-path courses, the project incorporates active-learning-based approaches and equity-based best practices, including culturally responsive pedagogy. Theoretical principles and empirical evidence support these techniques and have been shown to create an equitable classroom environment that reduces opportunity gaps, particularly in STEM, and promotes success for all students, regardless of socio-economic status, ethnicity, race, and gender.

Acknowledgments

This project is jointly sponsored by the College of Engineering and Computer Science and the Office of Undergraduate Studies at Sacramento State and by an NSF grant (DUE # 2235774).

References

[1] C. L. Dym, A. M. Agogino, O. Eris, D. D. Frey, and L. J. Leifer, “Engineering design thinking, teaching, and learning”, *J. Eng. Educ.*, vol. 94, no. 1, pp. 103–120, Jan. 2005.

[2] S. Rodenbusch, et al. “Early engagement in course-based research increases graduation rates and completion of science, engineering, and mathematics degrees,” *CBE life sciences education,* vol. 15, 2016, doi:10.1187/cbe.16-03-0117.

[3] C. D. Wilson, J. A. Taylor, S. M. Kowalski, and J. Carlson, “The relative effects and equity of inquiry-based and commonplace science teaching on students’ knowledge, reasoning, and argumentation,” *J. Res. Sci. Teach.*, 2009.

[4] C. Katie, M. Blum Michelle, M. Julie, and S.-C. C. Elizabeth, “A gateway course redesign working group model,” in *ASEE Annual Conference & Exposition. Salt Lake City*, Utah: ASEE Conferences, 2018.

[5] X. Chen, “STEM attrition: college students’ paths into and out of STEM fields (NCES 2014-001),” National Center for Education Statistics, Institute of Education Sciences, U.S. Department of Education. Washington, DC, 2013.

[6] Online Teaching Practices Toolkit, Association of College and University Educators. [Online]. Available: https://acue.org/inclusive-teaching-practices-toolkit.

[7] National Research Council. 2000. How People Learn: Brain, Mind, Experience, and School: Expanded Edition. Washington, DC: The National Academies Press. https://doi.org/10.17226/9853.

[8] P. Guo, N. Saab, L. Post, and W. Admiraal, "A review of project-based learning in higher education: Student outcomes and measures," *International Journal of Educational Research,* vol 102, 2020.

[9] M. Winzker, N. Bounif and C. Luppertz, "Improving first-year teaching with project-based learning and support of stem modules," *2020 IEEE Frontiers in Education Conference (FIE)*, Uppsala, Sweden, 2020, pp. 1-4, doi: 10.1109/FIE44824.2020.9274263.

[10] H. Nguyen , L. Wu, C. Fischer, G. Washington, and M. Warschauer, "Increasing success in college: Examining the impact of a project-based introductory engineering course," *Journal of Engineering Education*, vol. 109, pp. 384-401, 2020.

[11] Z. Zaini, "The scaffolding and investigation of thinking to calculus project in project based learning (PBL) activities," *Multica Science and Technology (MST) Journal,* vol. 1, pp. 61-71, 2021.

[12] S. Freeman, S. Eddy, M. McDonough, M. Smith, N. Okoroafor, H. Jordt, and M. Wenderoth, "Active learning increases student performance in science, engineering, and mathematics," *Proceedings of the National Academy of Sciences*, vol. 111, pp. 8410-15, 2014.

[13] S. Han, R. Capraro, and M. Capraro, "How science, technology, engineering, and mathematics project based learning affects high-need students in the U.S," *Learning and Individual Differences*, vol. 51 pp.157-66, 2016.

[14] K. El Gaidi, and T. Ekholm, "Contextualizing calculus with everyday examples to enhance conceptual learning," in the *2015 ASEE Annual Conference & Exposition*, June 2015, Seattle, Washington.

[15] S. Mayoral, A. Linton, H. Yousefi, and J. Huang, "Work in progress: implementing elements of engineering design into calculus," i*n the 2021 ASEE Virtual Annual Conference Content Access, Jul. 2021,* virtual conference. [online]. Available: https://peer.asee.org/38169.

[16] V.Tinto, "Dropout from higher-education: a theoretical-synthesis of recent-research," *Review of Educational-Research,* vol.-45, no.-1, pp-89-125, 1975.

[17] F. Herrera, and G. Sánchez, "Curando La Comunidad [Healing the Community]: community-centered stem identity," *Journal of Hispanic Higher Education*, vol. 21, pp. 135-50, 2022.

[18] G. Hoople, J. Mejia, D. Chen, and S. Lord, "Reimagining energy: deconstructing traditional engineering silos using culturally sustaining pedagogies," *in the 2018 American Society for Engineering Education Annual Conference Proceedings*, Salt Lake City, Utah, June 2018.

[19] L. Anglin, K. Anglin, P. L. Schumann, and J. A. Kaliski, "Improving the efficiency and effectiveness of grading through the use of computer-assisted grading rubrics," *Decision Sciences Journal of Innovative Education*, vol. 6, pp. 51-73.

[20] M. Mack, K. Winter, and M. Soto, "Culturally responsive strategies for reforming STEM higher education: Turning the TIDES on inequity," *Emerald Group Publishing*, 2022.

[21] D. Edelen, and S. B. Bush, "Moving toward inclusiveness in stem with culturally responsive teaching," *Kappa Delta Pi Record Journal*, vol. 57, pp. 115-19, 2021.

[22] V. Svihla, W. Lim, E. Esterly, I. Lee, M. Moses, P. Prescott, and T. Peele-Eady, "Designing for assets of diverse students enrolled in a freshman-level computer science for all course," *in the 124th ASEE Annual Conference & Exposition*, Columbus, USA, June 2017.

[23] P. Guo, J. Kim, and R. Rubin, "How video production affects student engagement: An empirical study of MOOC videos," *In Proceedings of the first ACM conference on Learning@ scale conference*, pp. 41-50, March 2014.

[24] N. Scagnoli, "7 things you should know about microlectures," in *Teaching and Learning Mobile Learning*. EduCase 2012. [Online]. Available: https://library.educause.edu/-/media/files/library/2012/11/eli7090-pdf.pdf

[25] B. Supiano, "It's not about the evidence anymore," *the Chronicle of Higher Education*, 2012. [Online]. Available: https://www.chronicle.com/article/its-not-about-the-evidence-anymore.

[26] D. Grewal, "Reducing the impact of negative stereotypes on the careers of minority and women scientists," *in the American Association for the Advancement of Science*, 2010. [Online]. Available: https://www.science.org/content/article/reducing-impact-negative-stereotypes-careers-minority-and-women-scientists.

[27] C. Staats, K. Capatosto, L. Tenney, S. Mamo, "State of the science: implicit bias review," *Kirwan Institute for the Study of Race and Ethnicity, The Ohio State University, 2017*. [Online]. Available: https://kirwaninstitute.osu.edu/sites/default/files/pdf/2017-implicit-bias-review.pdf

[28] D. Sue, "Microaggressions in everyday life: Race, gender, and sexual orientation," John Wiley & Sons, Hoboken, NJ, US 2010.

[29] G. Boysen, “Teacher and student perceptions of microaggressions in college classrooms,” *College Teaching* Journal, vol. 60, pp. 122-29, 2012.

[30] CSU Student Success Dashboard, [Online]. Available: https://calstate.edu/dashboard.