2026 ASEE ANNUAL CONFERENCE June 21–24, 2026 | Charlotte Convention Center, NC
Host Sponsor UNC Charlotte
Paper ID #50605

From Struggle to Strength: Equity-Centered Calculus Instruction for Engineering Students

Rafael Alberto Méndez-Romero
Dr. Lisa Bosman, Purdue University (West Lafayette, IN, USA)

Dr. Lisa Bosman, PhD in Industrial Engineering, is an Associate Professor in the Purdue Polytechnic Institute at Purdue University. Her engineering education research interests include entrepreneurially minded learning, interdisciplinary education, and faculty professional development.

Nidhi Kirani, Purdue University – West Lafayette (College of Engineering)

From Struggle to Strength: Equity-Centered Calculus Instruction for Engineering Students

Abstract: Engineering students often struggle to see the relevance of mathematics in their coursework, which can lead to disengagement and reduced persistence. To address this challenge, this Work-in-Progress project integrates a four-week, semester-ending intervention in a differential calculus course that focuses on themes of social justice and equity, aiming to connect mathematical concepts to real-world issues. The intervention was intentionally designed to promote productive struggle, encouraging students to grapple with complex, socially relevant problems while deepening their mathematical understanding. A quantitative design was employed, comprising retrospective pre- and post-surveys, and a final post-course survey. Preliminary findings suggest that students reported higher motivation, deeper conceptual understanding, and stronger connections between technical skills and societal applications. These results highlight the potential of equity-centered pedagogy and structured productive struggle to enhance student learning and engagement, while also broadening participation in engineering education. The study provides actionable evidence for instructors seeking innovative and inclusive practices that prepare students to apply technical knowledge to pressing global challenges.

1. Introduction

Engineering education often emphasizes efficiency, correctness, and rapid convergence on solutions [1]. While these priorities align with professional expectations, they can inadvertently short-circuit the very learning processes required for deep conceptual understanding. When students are consistently guided toward predefined methods, fully specified problem statements, and narrowly constrained solution paths, they may succeed procedurally while failing to develop adaptive expertise [2]. In such environments, learners come to view mathematics, particularly calculus, as a collection of disconnected techniques rather than a flexible language for reasoning about complex systems [3].

Using reverse logic, the absence of intentionally challenging, open-ended learning experiences reveals several persistent issues. Students may struggle to transfer mathematical knowledge to unfamiliar contexts, defaulting to pattern matching rather than sensemaking [4]. They may interpret difficulty as evidence of inability rather than as a normal and necessary part of learning, leading to reduced confidence and avoidance of challenging tasks. In engineering contexts, this can manifest as discomfort with ambiguity, overreliance on formulas, and limited engagement with real-world problems that do not present a single “correct” answer [5]. Collectively, these outcomes undermine the preparation of students for professional practice, where ill-structured problems, competing constraints, and social considerations are the norm rather than the exception [6].

To address these challenges, this study intentionally incorporated productive struggle into a differential calculus course through a semester-ending social justice and equity–focused project. Rather than treating calculus as an abstract prerequisite detached from societal concerns, the project positioned mathematical concepts as tools for interrogating real-world issues such as inequitable resource distribution, environmental exposure, or access to essential services.

Students were tasked with defining a socially relevant problem, identifying appropriate data or assumptions, and applying differential calculus concepts to analyze rates of change, optimization, or sensitivity within that context.

The project was deliberately designed to be open-ended and minimally scaffolded in its early stages, requiring students to wrestle with problem formulation, model selection, and interpretation of results. Instructional support was provided through iterative feedback, reflective prompts, and structured checkpoints, allowing students to persist through difficulty without being rescued from it. By embedding productive struggle within a socially meaningful context, the study sought not only deepen conceptual understanding of calculus but also to enhance students' sense of relevance, agency, and responsibility as future engineers.

The guiding research question is as follows: *How does participating in a social justice and equity-focused final project influence student perceptions of learning in a differential calculus class?*

The contribution of this work lies at the intersection of mathematics education, engineering pedagogy, and social justice. By examining student perceptions within a calculus course that foregrounds both productive struggle and societal relevance, this study provides empirical insight into how early engineering mathematics experiences can be reimagined to support deeper learning, persistence through challenge, and meaningful engagement with equity-oriented problems. The findings aim to inform instructional design strategies that better align foundational mathematics courses with the cognitive and ethical demands of contemporary engineering practice.

2. Background

Productive struggle is an instructional approach that encourages learners to engage with challenging problems before receiving explicit solutions [7]. It emphasizes grappling with difficulty as a path to deeper understanding rather than minimizing effort or confusion. Tasks are designed to be conceptually demanding yet accessible, with support that sustains effort without immediately resolving the challenge. The benefits of productive struggle include stronger conceptual understanding, improved knowledge retention, and greater transfer to new contexts [8]. Students develop flexible problem-solving strategies and construct connections among ideas. Experiencing and overcoming difficulty can also shift students' beliefs about learning, promoting persistence and resilience [9]. Challenges include initial student frustration or resistance, especially in mathematics and engineering, where guided instruction is often the norm [10]. Poorly designed tasks can overwhelm learners or reinforce misconceptions. Instructors must carefully balance support and autonomy, ensuring struggle remains productive rather than discouraging [11].

Calculus is foundational in engineering but often seen as abstract and procedural [12]. Integrating productive struggle reframes it as a tool for reasoning about real-world problems rather than memorizing formulas. Students are encouraged to interpret problems, choose representations, and justify solutions, deepening conceptual understanding. This approach helps engineering students develop adaptive expertise for ill-structured problems and enhances knowledge transfer across disciplines. By engaging with complex, realistic scenarios, learners connect mathematical concepts to technical, social, and ethical contexts [13]. Implementing productive struggle requires careful instructional design and clear alignment with learning objectives. When done thoughtfully, it transforms calculus from a gatekeeping requirement into a formative experience, supporting both mathematical competence and professional growth [14].

3. Methods

3.1 Intervention

This study employed a mixed-methods design to examine how integrating a social justice and equity–focused project into a Differential Calculus course influences student perceptions of learning and engagement. The intervention was implemented over four weeks at the end of the semester. The research sequence included (1) participant recruitment, (2) intervention implementation, (3) data collection through quantitative surveys and qualitative reflections, and (4) data analysis using both descriptive statistics and thematic coding.

3.2 Participants

Participants in this study were 25 students from a single section of a Differential Calculus course. Most were first- or second-year students majoring in applied mathematics, computer science, or engineering. Of these, 23 completed both surveys, and 22 provided usable reflections. Participation was voluntary, anonymous, and unrelated to course grading.

3.3 Data Collection Instruments

Upon completion of the project, participants responded to a retrospective post-then-pre survey (items are shown in Table 1) and a post-survey (items are shown in Table 2). In both surveys, participants were requested to identify to what extent they agreed with the statements (1 = Strong Disagree; 5 = Strongly Agree).

3.4 Data Analysis Procedure(s)

Quantitative analyses were conducted using IBM SPSS Statistics version 172 (30.0.0.0). Quantitative data were drawn from the retrospective post-then-pre survey and the post-course final-project survey. T-tests were conducted to test for statistically significant outcomes.

4. Results and Discussion

4.1 Curriculum Development: Perceived Learning Gains (Retrospective Post-then-Pre Survey)

Table 1 provides the results from analyzing the retrospective post-then-pre survey data (1 = Strong Disagree; 5 = Strongly Agree). To assess for statistically significant changes in students' self-reported learning and engagement, paired-samples t-tests were conducted with a significance threshold of $p < 0.05$. Six of the eight items were found to be statistically significant, indicating that students experienced measurable perceived learning gains across several aspects of the Differential Calculus course that integrated social justice and equity themes. However, it is important to note that all items showcased perceived learning gains, albeit two were not statistically significant.

The largest improvement was observed in students' understanding of how differential calculus can be applied to real-world problems, increasing from an average of 3.31 to 4.77 ($p < 0.001$). The second largest improvement was observed in students' comfort in discussing social justice issues in the classroom, increasing from an average of 3.77 to 4.69 ($p = 0.004$). The four other notable statistically significant perceived learning gains include empowerment to speak up against social justice ($p = 0.014$), enjoyment in learning perspectives and opinions of peers ($p = 0.025$), enjoyment in sharing perspectives and opinions of peers ($p = 0.006$), and confidence in verbal communication skills ($p = 0.047$). These findings suggest that students not only strengthened conceptual understanding but also grew in confidence connecting mathematics to societal contexts and collaborative learning.

Table 1. Results for Perceived Learning Gains: Retrospective Post-then-Pre Survey

Statement	BEFORE (average)	AFTER (average)	T-Test (p-value)
I understand how differential calculus can be used to solve real-world problems.	3.31	4.77	<0.001**
I feel comfortable discussing social justice issues in the classroom.	3.77	4.69	0.004**
I feel empowered to speak up against social injustice in my community.	3.54	4.38	0.014*
I seek out a variety of information sources to supplement my learning.	4.08	4.54	0.082
I enjoy learning the perspectives and opinions of my peers.	4.00	4.62	0.025*
I enjoy sharing my perspectives and opinions with my peers.	3.85	4.54	0.006**
I am confident in my written communication skills.	3.69	4.15	0.139
I am confident in my verbal communication skills.	4.08	4.62	0.047*

*p-value significance: **<0.01; *<0.05*

4.2 Curriculum Development: Perceived Learning Gains (Final Project Impact)

Table 2 summarizes students' perceptions of the final project (1 = Strong Disagree; 5 = Strongly Agree)—a four-week, equity-focused assignment designed to synthesize differential calculus concepts through applied, team-based work. Mean scores across all items ranged from 3.63 to 4.13 on a five-point scale, showing overall positive evaluations. Students most strongly agreed that the project was informative ($M = 4.13$) and enhanced their learning in the course ($M = 4.06$). Items related to real-world relevance, self-development, belonging, and critical thinking also scored favorably ($M \approx 3.8$–3.9). Overall, the data indicate that the integrative final project effectively promoted both technical comprehension and social-contextual engagement, reinforcing the value of embedding equity-centered applications into STEM curriculum.

Table 2. Descriptive Statistic Results for Final Project Impact

Statement	N	Min	Max	Mean	Std Dev
The final project increased my interest in this course.	16	1	5	3.69	1.493
The final project increased my learning in this course.	16	1	5	4.06	1.569
The final project offered insights for the real world and my own life.	16	1	5	3.88	1.586
The final project was informative.	16	1	5	4.13	1.586
The final project improved my communication skills.	16	1	5	3.63	1.500
The team-based aspect of the final project gave me a sense of belonging in the course by getting to know other course participants.	16	1	5	3.81	1.559
The final project offered learning that was important to my self-development.	16	1	5	3.81	1.515
The final project expanded my knowledge in differential calculus applications.	16	1	5	3.94	1.482
The final project improved my critical thinking skills.	16	1	5	3.94	1.482
The final project directions and expectations were easy to understand.	16	1	5	3.88	1.408

5. Conclusion

In conclusion, participation in the four-week, social justice–centered final project appeared to positively influence students' perceptions of their learning in differential calculus, particularly in understanding real-world applications and engaging with equity issues. Students reported statistically significant gains in seeing how differential calculus can address real-world problems, comfort discussing social justice, empowerment to speak up against injustice, and confidence in verbal communication, alongside generally favorable views of the project's impact on interest, learning, and critical thinking. These results suggest that instructors of early engineering mathematics should intentionally design equity-centered projects that foreground productive struggle (such as open-ended, team-based investigations of socially relevant problems) and that programs should support faculty in developing and scaling such experiences across calculus sequences to strengthen conceptual understanding, communication, and students' sense of relevance and agency.

This work is limited by its focus on a single course section within one program, reliance on self-reported survey data, and a modest sample size for some instruments, which constrain generalizability and prevent strong causal claims. Future research should employ multi-institutional designs, incorporate longitudinal and performance-based measures of learning, and more systematically examine how different forms of productive struggle and social justice framing influence diverse students' experiences, persistence, and identity development in foundational engineering mathematics.

6. References

[1] A. K. Noor, "Envisioning engineering education and practice in the coming intelligence convergence era—a complex adaptive systems approach," *Central European Journal of Engineering,* vol. 3, no. 4, pp. 606-619, 2013.

[2] T. Martin, T. Benton, W. McKenna, and P. Ko, "Transfer of adaptive expertise to transform engineering education," in *2010 Annual Conference & Exposition*, 2010, pp. 15.1277. 1-15.1277. 24.

[3] Y. Solomon and T. Croft, "Understanding undergraduate disengagement from mathematics: Addressing alienation," *International Journal of Educational Research,* vol. 79, pp. 267-276, 2016.

[4] C. Granberg, "Discovering and addressing errors during mathematics problem-solving—A productive struggle?," *The Journal of Mathematical Behavior,* vol. 42, pp. 33-48, 2016.

[5] S. G. Puente and J. Jansen, "Exploring students' engineering designs through open-ended assignments," *European Journal of Engineering Education,* vol. 42, no. 1, pp. 109-125, 2017.

[6] S. Akinci-Ceylan, K. S. Cetin, and B. Ahn, "Faculty Perceptions on Teaching Ill-Structured Problems in Engineering Classrooms: A Conceptual Model for Enhancing Comfort and Support," *Journal of Civil Engineering Education,* vol. 152, no. 2, p. 04025018, 2026.

[7] C. Afitu and M. Bini, "Productive struggle," *Vinculum,* vol. 58, no. 2, pp. 9-11, 2021.

[8] V. Nachtigall, K. Serova, and N. Rummel, "When failure fails to be productive: Probing the effectiveness of productive failure for learning beyond STEM domains," *Instructional Science,* vol. 48, no. 6, pp. 651-697, 2020.

[9] E. A. Skinner, J. P. Graham, H. Brule, N. Rickert, and T. A. Kindermann, "“I get knocked down but I get up again”: Integrative frameworks for studying the development of motivational resilience in school," *International Journal of Behavioral Development,* vol. 44, no. 4, pp. 290-300, 2020.

[10] S. Tharayil *et al.*, "Strategies to mitigate student resistance to active learning," *International journal of STEM education,* vol. 5, no. 1, p. 7, 2018.

[11] F. Basri, "Factors influencing learner autonomy and autonomy support in a faculty of education," *Teaching in Higher Education,* vol. 28, no. 2, pp. 270-285, 2023.

[12] M. A. Tallman, M. P. Carlson, D. M. Bressoud, and M. Pearson, "A characterization of calculus I final exams in US colleges and universities," *International Journal of Research in Undergraduate Mathematics Education,* vol. 2, no. 1, pp. 105-133, 2016.

[13] J. Register, M. Stephan, and D. Pugalee, "Ethical reasoning in mathematics: New directions for didactics in US mathematics education," *Mathematics,* vol. 9, no. 8, p. 799, 2021.

[14] N. Dick *et al.*, "A transformative approach to collaborative learning for higher education," *The International Journal of Learning in Higher Education,* vol. 29, no. 2, p. 189, 2022.