2026 ASEE ANNUAL CONFERENCE June 21–24, 2026 | Charlotte Convention Center, NC
Host Sponsor UNC Charlotte
Paper ID #52896

# Heterogeneity vs homogeneity of math course enrollment in first year engineering design teams

**Madalyn Wilson-Fetrow, University of New Mexico**
**Prof. Anjali Mulchandani, University of New Mexico**

Dr. Anjali Mulchandani is an Assistant Professor in the Department of Civil, Construction and Environmental Engineering at the University of New Mexico.

# Heterogeneity vs homogeneity of math course enrollment in first-year engineering design teams

**Abstract**
In this Complete Research Paper, we explored how the math course students are enrolled in impacts engineering identity and self-efficacy across first-year engineering courses across two departments when engaged in design challenges. We conducted surveys in two first-year engineering courses (one in civil and construction engineering and one in chemical and biological engineering). Each course has one design challenge that groups students by other attributes besides math courses (heterogeneous) and another that groups students in the same or similar math courses (homogeneous). We define "on-track for math" as enrolled in Calculus I or above during the first semester (Fall) and Calculus II or above in the second semester (Spring), while "pre-track for math" indicates enrollment in any pre-requisite math class or not currently enrolled or never enrolled in a math class at the college level. Our findings show that students who are on-track in math start their engineering program with a higher engineering identity compared to students who are pre-track. However, our key finding is that when placed in teams with peers in the same or similar math courses, pre-track students showed a significantly greater increase in engineering identity than their on-track peers.

**Introduction and Background**
First-year engineering students may often enter their engineering degree programs at varying math levels, ranging from Foundational Math or Pre-Algebra, Algebra, Trigonometry, Pre-Calculus, Calculus I, Calculus II, Calculus III, and above [1]. While entering a first-year program while enrolled in Calculus may indicate "on-track for math," many students can be 1-5 courses behind, i.e., "pre-track." There are a myriad of reasons for this phenomenon, e.g., lack of access to advanced math courses in middle and high schools, and lack of support structures such as tutoring and extra-curricular math opportunities (e.g., MathCounts, Academic Decathlon, Kumon) [2], [3]. Math access may be limited at rural schools with limited resources, leading to students of minority backgrounds not having the same level of math preparation or readiness as privileged students at urban high schools [4], [5], [6].

Inclusive educational programming and practices such as bridge programs, tutoring and foundational math courses that are offered to students before or during their first year can provide pathways to success in engineering programs and lead to positive outcomes such as increased self-efficacy and retention [7], [8] . Several engineering programs in the United States offer a pre-engineering pathway that enables students to take preparatory prerequisites before admission to the engineering major, while already enrolled in college. Often, students take a first-year engineering design course while co-enrolled in pre-track math courses. This presents an opportunity and a challenge for instructors: how to design a first-year engineering design course for a cohort of students with a wide range of math backgrounds, while still providing all of them opportunities to practice math application and engineering design skills?

Engineering identity consistently predicts both persistence intentions and long-term persistence itself (both degree completion and continued work after graduation) [9]. However, engineering identity is impacted by more than just the desire to be an engineer. Students who are minoritized in engineering often struggle to identify as engineers in the first place and feel less so as they encounter classes that are exclusionary or fail to account for students' diverse experiences and contexts [10], [11]. Faculty who have expectations about what an engineering student should be can communicate that students who don't fit that vision don't belong [12]. This results in a less diverse community. This is true for math preparedness as well. As departments and faculty assume all or most students are in a certain level of math, pre-track students may leave engineering due to a belief that if they are not "advanced" in math, they can never be successful as engineers.

Thus, the broad range of math preparedness within a single course offers a unique case study of student retention vs. attrition. It has been posited that students drop out of engineering majors due to challenges faced while completing math pre-requisites. The objective of this work is to understand the influence of different strategies that first-year engineering design course instructors can use to support students enrolled in a range of math courses. We ask the following research questions:

1. To what extent does the race/ethnicity of students impact whether students are in higher-level math?
2. To what extent does forming teams with heterogeneous or homogeneous math courses support first-year students in completing design challenges to develop engineering identity?

**Methods**

The research took place at a Hispanic-serving R1 university in the southwestern United States, in two introductory engineering courses: a civil and construction engineering (CCE) course in Fall 2025 and a chemical and biological engineering (CBE) course in Spring 2025. Both courses consisted of two design challenges. In both courses and following IRB approval, homogeneous teams were formed by surveying students about their current and previous math classes, then grouping by shared math courses into groups of three or four. In cases where there were unequal numbers of students in a course, teams contained students in closely related courses (such as trigonometry and pre-calculus).

In the CCE course, the first design challenge allows students to choose their own groups, therefore math enrollment was not controlled for and could be heterogeneous or homogeneous. During the design challenge, teams developed and tested a solution to remediate acid mine drainage in the Southwestern United States. They considered stakeholder perspectives, including community members impacted by mining waste, government agencies responsible for remediation efforts, and scientists and engineers developing remediation solutions. They plotted results of a laboratory experiment to neutralize the pH of acidic water, and compared findings to whole-course data to suggest an optimal solution. The second design challenge had students intentionally grouped by the same or similar math course. During the design challenge, students worked on an aspect of the American Society of Civil Engineering's concrete canoe challenge, in which teams developed and tested a concrete mix design and calculated the volume of materials and the cost to build a concrete canoe. No instructions were given for calculating the canoe's volume, and responses ranged from simple rectangular prisms to numerical integration by splitting the canoe into small shapes and summing their volumes.

In the CBE course, the first design challenge groups students into groups where all students are in similar or closely related math courses. During the design challenge, students selected a math or physics concept that they felt was irrelevant or useless to engineering. Then, teams developed an instructional activity to teach the concept in ways relevant to their daily lives and to engineers' needs. They had to both work through math concepts and incorporate interactive or hands-on components to support authentic learning before demonstrating their activity to peers and math faculty. The second design challenge had teams grouped without accounting for the math level. Teams then developed a green energy solution for a community they had some connection to. They considered the possibilities of solar-hydro energy through an experiment where they optimized turbines for either wind or water. They then analyzed whole-course data in an open-ended assignment in which students had to determine the best turbine configuration. They then explored other solutions (such as nuclear or solar) and analyzed the potential pros and cons before writing a proposal for implementing their designs in their specific community.

We deployed a survey at the beginning and end of the courses, as well as after the first design challenge. This survey included demographic information, identity questions, and intent to persist in the degree and in an engineering field after graduation [13]. The survey was previously validated to confirm the identity and persistence constructs. Table 1 shows the survey questions.

**Table 1: Survey questions used across both courses. All questions are on a seven-point Likert scale**

| | |
|---|---|
| Engineering Identity | Please rate your agreement with the statements below:<br>● My parents, relatives, and friends see me as an engineering person<br>● My instructors see me as an engineering person<br>● I feel like I belong in engineering |
| Engineering Self-Efficacy | How unconfident or confident are you that you can:<br>● Learn the content taught in your engineering-related courses?<br>● Master the content in even the most challenging engineering course?<br>● Earn a good grade in your engineering courses? |
| Demographic & contextual questions | What is your academic standing? (First-year/Freshman; Sophomore; Junior; Senior; Other:)<br><br>Which best describes your gender identity? (Male; Female; Indigenous or other cultural gender minority identity (e.g., two-spirit); Something else (e.g., gender fluid, non-binary); Other:)<br><br>What is your race? (Select one or more: American Indian, Native American, or Alaska Native; Asian; African American, African, or Black; Middle Eastern or North African; Native Hawaiian or Other Pacific Islander; White; Other:) |

To analyze the impact of student math level, we coded math courses from most to least advanced along the expected math track, and student team math level from most to least advanced. To understand how demographics may impact students, we created two categorical variables: privileged and minoritized race/ethnicity, and minoritized gender. We defined students who identified as men and both white and Asian students as privileged in engineering. In both cases, students have a wide range of experiences that cannot be assumed to be the same. However, due to low rates of some identity responses and the possibility of identifying anonymous students in the data, we chose to create variables that instead focused on relationships with power structures and on how they are minoritized or privileged.

To determine the extent of the impact of race/ethnicity on current math course enrollment, we employed a chi-squared test of difference. We then conducted linear regression analysis across the courses to determine the impact of student team and math course on engineering identity. We developed four models that consider engineering identity across both design challenges (homogeneous and heterogeneous math teams) in both courses. We tested the assumptions of normality, linearity, homoscedasticity, and independence and found no major violations within the tolerance limits of least squares. regression.

**Results**

To answer the first research question, we conducted chi-squared test of difference. Table 2 shows the percentages of students on-track and pre-track in math. We define on-track as enrolled in Calculus I or above during the first semester (Fall) and Calculus II or above in the second semester (Spring), while pre-track indicates enrollment in any pre-requisite math class or not currently enrolled or never enrolled in a math class at the college level. We included students who were not taking a math class because they had previously completed all required math courses as on-track. We found that in both courses, there was a significant difference in the placement of minoritized and privileged students in on-track or pre-track math courses.

**Table 2: On-track and pre-track students by course and by race/ethnicity privilege**

| | | Minoritized | Privileged | $\chi^2$ | p |
|---|---|---|---|---|---|
| CBE | N = 64 | | | | |
| | Pre-Track | 82% (32) | 44% (11) | 17.12 | 0.0002 |
| | On-Track | 18% (7) | 56% (14) | 13.08 | 0.001 |
| CCE | N = 68 | | | | |
| | Pre-Track | 76% (52) | 44% (30) | 9.11 | 0.0105 |
| | On-Track | 24% (16) | 56% (38) | 8.17 | 0.017 |

We conducted a series of regressions to understand the relationships between engineering identity and our constructs. Table 3 presents regression models 1 and 2 that identify the CCE course's design challenges. In model 1, beginning-of-design-challenge engineering identity, self-efficacy, and math level for CCE students all significantly predict end-of-design-challenge engineering identity ($F(5, 61) = 14.33$, $p < 0.01$, $r^2 = 0.31$). In this case of the design challenge teams with heterogeneous grouping of math enrollment, CCE students in higher-level math had a greater increase in their engineering identity than their peers.

In model 2, variance in final engineering identity for CCE students was significantly predicted by math level, self-efficacy, engineering identity at the beginning of the design challenge (at the mid survey), and team experience level ($F(6, 61) = 14.33$, $p < 0.001$, $r^2 = 0.29$). We did not include the team in model 1 as these teams were grouped without regard for math level and so could not be considered a non-categorical variable. In model 2 for the design challenge teams that were grouped by homogeneous math enrollment, CCE students in less-advanced math courses benefited significantly more and had a greater increase in their identity than their peers.

**Table 3: Models 1 and 2 explaining variance in engineering identity in the CCE course**

| | B | SE | t value | p value |
|---|---|---|---|---|
| Model 1: Heterogeneous Math Teams (Outcome: mid-course engineering identity) | | | | |
| (Intercept) | 0.82 | 0.61 | 1.35 | 0.18 |
| Race/ethnicity | 0.07 | 0.11 | 1.90 | 0.06 |
| Gender | 0.03 | 0.07 | 0.35 | 0.72 |
| Math level | 0.01 | 0.12 | 2.04 | 0.04* |
| Engineering identity, pre | 0.33 | 0.08 | 4.01 | <0.001* |
| Self-efficacy, mid | 0.30 | 0.08 | 3.92 | <0.001* |
| Model 2: Homogeneous Math Teams (Outcome: end-of-course engineering identity) | | | | |
| (Intercept) | -0.32 | 0.68 | -0.48 | 0.64 |
| Race/ethnicity | 0.02 | 0.15 | 0.12 | 0.91 |
| Gender | 0.03 | 0.15 | 0.17 | 0.87 |
| Math level | -0.62 | 0.26 | -2.33 | 0.02* |
| Engineering identity, mid | 0.50 | 0.09 | 5.82 | <0.001* |

| | | | | |
|---|---|---|---|---|
| Self-efficacy, post | 0.36 | 0.08 | 4.33 | <0.001* |
| Team level | -0.31 | 0.10 | -2.02 | 0.05* |

We conducted the same analysis regarding the CBE course as well. Table 4 shows the two models, 3 and 4, that explain variance in engineering identity during the two design challenges. In model 3 (the design challenge with homogeneous math-level teams), we found that beginning-of-design-challenge engineering identity, self-efficacy, and team for CBE students significantly explained variance in engineering identity at the end of the design challenge ($F(6, 57) = 5.048$, $p = 0.07$, $r^2 = 0.39$). In this case, student design teams grouped by homogeneous math enrollment, CBE students in higher math had fewer increases in engineering identity than their peers. These results match the findings from model 2 for CCE students. In model 4, for heterogeneously grouped CBE students, we found that beginning-of-design-challenge engineering identity and self-efficacy significantly predicted variance in end-of-design-challenge engineering identity ($F(5, 57) = 6.46$, $p < 0.001$, $r^2 = 0.21$), also aligning with the results in CCE, from model 1.

**Table 4: Models 3 and 4 explaining variance in engineering identity in CBE**

| | B | SE | t value | p value |
|---|---|---|---|---|
| Model 3: Homogeneous Math Teams (Outcome: mid-course engineering identity) | | | | |
| (Intercept) | 0.31 | 0.72 | 0.43 | 0.67 |
| Race/ethnicity | -0.19 | 0.16 | -1.18 | 0.24 |
| Gender | 0.39 | 0.22 | 1.75 | 0.08 |
| Math level | -0.33 | 0.08 | -4.20 | <0.001* |
| Engineering identity, pre | 0.46 | 0.10 | 4.71 | <0.001* |
| Self-efficacy, mid | 0.05 | 0.09 | 0.58 | 0.56 |
| Team level | -0.23 | 0.11 | -2.00 | 0.05* |
| Model 4: Heterogeneous Math Teams (Outcome: end-of-course engineering identity) | | | | |
| (Intercept) | 5.15 | 0.57 | 8.96 | <0.001* |
| Race/ethnicity | 0.38 | 0.33 | 1.13 | 0.26 |
| Gender | 0.08 | 0.10 | 0.73 | 0.47 |

| | | | | |
|---|---|---|---|---|
| Math level | 0.11 | 0.11 | 1.01 | 0.31 |
| Engineering identity, mid | 0.31 | 0.40 | 2.87 | <0.001* |
| Self-efficacy, post | 0.28 | 0.10 | 2.92 | <0.001* |

**Discussion**

Is the level of math of a first-year student critical to a student's success in the first-year class and identity as an engineer? Many traditional engineering programs are designed to be completed within 4-5 years, with students starting in Calculus I in their first semester or quarter. Non-traditional students, minoritized students, students who went to high school in rural communities, and students whose high schools did not prioritize advanced STEM courses may often not be calculus-ready. In fact, at our university, only 20% of minoritized first-year students in civil and chemical engineering programs are on track in math, compared to over 50% of privileged students.

Our findings show that students who are on track in math enter their engineering program with higher engineering identity than students who are pre-track. However, our key finding is that these pre-track students have statistically greater increases in identity from the beginning to end of the first-year course in comparison to their on-track peers.

What can instructors do to maintain a balance between supporting and challenging students who are on-track or ahead-of-track in math who are co-enrolled with pre-track students? First-year engineering courses often feature design challenges that are ill-structured (as opposed to well-structured), where students solve open-ended problems with no defined method or solution. These design challenges can be crafted by the instructor to provide equal opportunity for math-based problem-solving to all students, regardless of their math foundation and course level. For example, rather than a problem stating, "solve for the area under the curve," which would have a calculus-based answer, the problem can state, "solve for the volume of an irregular object using any method." Students enrolled in trigonometry can choose to break the object into smaller discernible shapes whose volume can be individually calculated, while calculus students can apply principles of integration. Both of these solutions allow for the development of a connection between mathematics concepts and engineering thinking.

Our findings show that grouping students by homogeneous math enrollment can be beneficial, especially when the design challenge involves deep involvement and deep engagement with math concepts. While homogenous grouping can have significant benefits to identity, heterogeneous grouping enables students to meet one another and collaborate across a range of personal and enrollment backgrounds.

These results do come with limitations and potential for future work. For one, while it is clear that each of these design challenges was effective, it is unclear how the very distinct nature of the implementations may impact differently from each other, and how the interaction effect of race/ethnicity and math level may impact how each design challenge supports minoritized students. Therefore, future work should use multiple linear regression to account for the interactions among the different design challenges, the repeated-measures nature of the data, and the relationship between math level and minoritized student identities. We also did not explore other potential outcomes in this paper, including engineering self-efficacy and persistence intentions, which may shed further light on the joint benefits of having both homogeneous and heterogeneous design challenges. Finally, this work would benefit from longitudinal data that tracks attrition within these contexts.

**Acknowledgements**
We gratefully acknowledge support from the National Science Foundation Award #1751369 and the University of New Mexico School of Engineering Teaching Innovation Award.

**References**

[1] S. Donohue Jobe *et al.*, "Math Preparedness: How first year civil engineering, construction engineering, and construction management students approach math-based design challenges," in *2025 ASEE Annual Conference & Exposition Proceedings*, Montreal, Quebec, Canada: ASEE Conferences, Jun. 2025, p. 56961. doi: 10.18260/1-2--56961.
[2] M. Baker, I. Morgan, and G. Wade, "Opportunities Denied: High Achieving Black and Latino Students Lack Access to Advanced Math," Education Trust, Dec. 2023. Accessed: Jan. 20, 2026. [Online]. Available: https://eric.ed.gov/?id=ED641831
[3] M. L. Wronowski, M. Thornton, B. Razavi-Maleki, A. W. Witcher, and B. J. Duarte, "Beyond Tracking: The Relationship of Opportunity to Learn and Diminished Math Outcomes for U.S. High School Students," *Teach. Coll. Rec.*, vol. 124, no. 6, pp. 196–224, Jun. 2022, doi: 10.1177/01614681221113473.
[4] G. R. Bertoline, "The Engineering Mindset Report: A vision for change in undergraduate engineering and engineering technology education," American Society of Engineering Education, 2024. [Online]. Available: https://sites.asee.org/fpd/wp-content/uploads/sites/5/2025/08/ASEE-FPD-Paper-Template-2026.pdf
[5] P. V. Anderson *et al.*, "CS/SE Instructors Can Improve Student Writing without Reducing Class Time Devoted to Technical Content: Experimental Results," in *2015 IEEE/ACM 37th IEEE International Conference on Software Engineering*, May 2015, pp. 455–464. doi: 10.1109/ICSE.2015.178.
[6] K. Leithwood and D. Jantzi, "A Review of Empirical Evidence About School Size Effects: A Policy Perspective," *Rev. Educ. Res.*, vol. 79, no. 1, pp. 464–490, Mar. 2009, doi: 10.3102/0034654308326158.
[7] C. Papadopoulos and J. Reisel, "Do Students In Summer Bridge Programs Successfully Improve Math Placement And Persist? A Meta Analysis.," in *2008 Annual Conference & Exposition Proceedings*, Pittsburgh, Pennsylvania: ASEE Conferences, Jun. 2008, p. 13.447.1-13.447.8. doi: 10.18260/1-2--3956.
[8] J. M. Raines, "FirstSTEP: A preliminary review of the effects of a summer bridge program on pre-college STEM majors," *J. STEM Educ. Innov. Res.*, vol. 13, no. 1, Jan. 2012, Accessed: Jan. 20, 2026. [Online]. Available: https://www.jstem.org/jstem/index.php/JSTEM/article/view/1682
[9] M. M. Chemers, E. L. Zurbriggen, M. Syed, B. K. Goza, and S. Bearman, "The Role of Efficacy and Identity in Science Career Commitment Among Underrepresented Minority

Students," *J. Soc. Issues*, vol. 67, no. 3, pp. 469–491, 2011, doi: 10.1111/j.1540-4560.2011.01710.x.
[10] S. L. McAlexander, K. McCance, M. R. Blanchard, and R. A. Venditti, "Investigating the Experiences, Beliefs, and Career Intentions of Historically Underrepresented Science and Engineering Undergraduates Engaged in an Academic and Internship Program," *Sustainability*, vol. 14, no. 3, Jan. 2022, doi: 10.3390/su14031486.
[11] S. González-Pérez, M. Martínez-Martínez, V. Rey-Paredes, and E. Cifre, "I am done with this! Women dropping out of engineering majors," *Front. Psychol.*, vol. 13, Aug. 2022, doi: 10.3389/fpsyg.2022.918439.
[12] L. Pedraza and R. Chen, "Examining Motivator Factors of STEM Undergraduate Persistence through Two-Factor Theory," *J. High. Educ.*, vol. 93, no. 4, pp. 532–558, Jun. 2022, doi: 10.1080/00221546.2021.1999722.
[13] M. Wilson-Fetrow, V. Svihla, and A. Olewnik, "Confirmatory factor analysis of the framing agency survey," presented at the 2023 ASEE Annual Conference & Exposition, Jun. 2023. Accessed: Feb. 08, 2024. [Online]. Available: https://peer.asee.org/confirmatory-factor-analysis-of-the-framing-agency-survey