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Unlocking Success in Calculus for Engineering Majors: Impact of Engagement Tactics for Underrepresented Undergraduate Engineering Students

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Unlocking Success in Calculus for Engineering Majors: Impact of Engagement Tactics for Underrepresented Engineering Students

Performance in calculus courses is often considered a significant barrier to the academic progress of students pursuing STEM (Science, Technology, Engineering, and Mathematics) majors. This challenge is particularly pronounced among disadvantaged groups, such as underrepresented minoritized students (URMs) and first-generation college students [1,2]. To address this issue, existing literature and guidance emphasize the importance of investigating psychosocial factors that can enhance resilience, persistence, and positive self-concepts within STEM fields including engineering [3,4]. Much of the extant research in this area involves universities with small proportions of URMs. Thus, continued study of the impact of these factors on more diverse student populations is also necessary to better capture the calculus experience of URM engineering majors. The purpose of the study was to examine student and classroom-level factors that influence course performance measured by course grade. This study focused on two engineering-related psychosocial factors: (1) engineering self-efficacy and (2) engineering sense of belonging, and three mathematics-specific psychological factors which we refer to as math motivators, (1) math interest, (2) self-concept, and (3) anxiety. Classroom level factors included active engagement practices, proportion of females, proportion of URMs students and proportion of first-generation students in classes.

Psychosocial Factors Influencing Course Performance

STEM Self-Efficacy

STEM self-efficacy, defined as an individual's belief in their ability to excel in STEM tasks and activities [1], plays a pivotal role in shaping students' attitudes and behaviors in STEM fields. Anticipations of personal efficacy dictate the initiation, extent, and sustainability of coping behavior when faced with challenges and adverse experiences [1]. This belief is influenced by prior experiences, accomplishments, as well as social and environmental factors [2]. High STEM self-efficacy levels lead to increased persistence and motivation in STEM-related activities, ultimately contributing to the development of STEM interest [3]. Furthermore, self-efficacy expectations significantly impact goal setting, activity choice, effort expenditure, and persistence [3]. Research has consistently supported models linking expectancy and values to various performance and choice outcomes [3]. In STEM disciplines, personal academic expectations predict subsequent performance, course enrollment, and occupational aspirations [2]. Efficacy expectations determine the extent of effort and persistence in the face of obstacles, with stronger perceived self-efficacy correlating with more active efforts [3]. The extant literature on the impact of STEM self-efficacy focuses on predicting course performance within the same discipline therefore it is silent on the extent to which science or engineering self-efficacy impacts calculus course performance. This study aims to address this gap in the literature by examining the extent to which engineering self-efficacy has a direct impact on calculus grades.

Math Interest

Math interest represents an individual's level of enjoyment, curiosity, and attraction towards STEM subjects and activities [6]. This motivational variable characterizes the psychological inclination to actively engage or repeatedly engage with specific categories of objects, events, or ideas over time [12]. In the context of STEM, a strong interest in math can significantly impact students' comprehension, effort, and preferences for feedback [5]. Understanding the development and maintenance of interest in a subject area is crucial for supporting student engagement [6]. Math interest is considered a key motivator in STEM learning contexts and has been strongly correlated with positive outcomes in mathematics and science [7]. Students with a heightened interest in a subject are more likely to engage in meaningful learning, demonstrate increased attentiveness, willingness to invest greater effort, and enhanced abilities to pursue and achieve goals [8]. Interest is not limited to specific gender, racial, ethnic, or social groups and has a universal basis, suggesting that everyone can develop some level of interest in the subjects they are learning [12]. Therefore, fostering math interest is crucial for motivating individuals to pursue engineering careers and engage in engineering learning [9]. Moreover, interest plays a pivotal role in the development of a positive STEM self-concept [8]. When individuals have an interest in STEM, they are more likely to seek out information and opportunities to engage in STEM activities, further contributing to their self-concept [8]. Therefore, we expected math interest to impact course grades, even after accounting for engineering self-efficacy.

Math Self-Concept

Math self-concept relates to an individual's self-perception of their competence and proficiency in mathematics [13]. It begins to develop early on and becomes increasingly related to interest and performance due to cumulative experiences, cognitive maturity, and autonomy in managing one's time [14]. A positive math self-concept is associated with intrinsic motivation, while diminished self-concept may lead to reduced interest and performance in mathematics [15]. Research has shown a positive relationship between self-concept and STEM sense of belonging and STEM identity, which, in turn, was related to individuals' likelihood of pursuing STEM fields, including engineering [18]. Students with higher math self-concept are more likely to be interested in math [18]. Therefore, we hypothesized that math self-concept positively impacts calculus grades.

Math Anxiety

Math anxiety, a common academic emotion, refers to the adverse emotional reactions such as fear, tension, nervousness, and disconnect in anticipation of situations demanding the application of mathematical knowledge [19]. While a certain level of anxiety can aid the learning process, excessive math anxiety can impede optimal learning outcomes, resulting in underachievement [21]. Calculus, a fundamental subject in engineering degrees, can trigger high levels of math anxiety, which, in turn, contributes to underperformance and even withdrawal from engineering majors [21]. Furthermore, anxiety influences academic engagement and the use of effective learning strategies [23]. Therefore, identifying appropriate strategies in the classroom to alleviate anxiety and enhance mathematical achievement is crucial [25].

Classroom-Level Factors Influencing Course Performance

In addition to psychosocial factors, classroom-level factors also significantly impact students' performance in calculus courses.

Active Engagement Practices

A growing body of scholarship has advocated for the adoption of active learning strategies in higher education, especially within STEM disciplines. Active learning refers to an educational approach where students actively participate in activities such as reading, writing, discussions, or problem-solving that promote analysis, synthesis, reflection, and evaluation of the material being taught [38]. This approach includes a range of teaching methods such as brief reflective writing assignments, think-pair-share activities, flipped classroom models, inquiry-based learning, and cooperative learning strategies. These methods not only enhance students' engagement and personal commitment to their studies but also improve motivation, enjoyment, depth of learning, critical thinking abilities, as well as retention rates and academic performance in classroom settings. Classrooms that offer students the chance to engage in mathematical exploration, communication, and collaborative problem-solving, while also providing feedback from both instructors and peers, tend to have a beneficial impact on the learning outcomes [39]

Further, active engagement practices within the classroom are crucial for fostering a positive learning environment [26]. These practices promote student participation, critical thinking, and a deeper understanding of the subject matter [26]. Active engagement can prepare students better for STEM careers by enhancing their mathematical skills and confidence [38]. Therefore, it is essential to consider the impact of active engagement practices on calculus grades [26].

Classroom Composition

The composition of the student body in calculus courses can also influence students' performance. Several factors related to the composition of the student body, such as diversity (racial, ethnic, gender), the level of preparedness of students, and the presence of peers who may serve as role models or sources of competition, have been studied for their impact on student outcomes. The performance and behaviors of peers can significantly impact an individual student's academic outcomes. For instance, students might perform better when surrounded by high-achieving peers due to positive peer pressure, enhanced learning environments, or increased motivation to match peers' performance levels.

A diverse student body in terms of race, ethnicity, and gender can enhance learning experiences by exposing students to a variety of perspectives and problem-solving approaches. Research suggests that such diversity can improve cognitive skills, such as critical thinking and problem solving [40,41,42]. For example, research has indicated that the gender composition of a class can affect outcomes, particularly in fields traditionally dominated by males such as engineering. The socioeconomic status of the student body can also play a role. Students from higher socioeconomic backgrounds often have more access to resources and support systems outside of school, which can influence their performance in class. Conversely, a more socioeconomically diverse classroom might provide a richer variety of perspectives but also requires more attention to addressing disparities in student preparation and access to resources.

Context of the Study

This research is based on a joint effort by two Hispanic Serving Institutions (HSIs) in the southwest aiming at the curricular overhaul of calculus courses for engineering students. Calculus is the study of change, providing a framework for simulating dynamic systems and deriving predictions from these simulations. Traditional calculus teaching on our campuses and broadly in higher education employs a lecture model, concentrating on mathematical procedures, especially the computation of derivatives and integrals, with less emphasis on interactive learning. Such courses usually focus on the mechanics of calculation, neglecting the underlying reasons and real-world applications of these computations. This often results in a lack of motivation and engagement among students, particularly URMs in STEM, further widening the achievement and retention gap in STEM fields for URMs and first-generation college students.

The reformed curriculum aims to balance (i) motivating the need for calculus and its methods, (ii) equipping students with the ability to tackle real-world problems using calculus, and (iii) ensuring proficiency in calculus techniques. The reform involves (a) incorporating active learning techniques, (b) fostering a sense of belonging in STEM through strategic practices, (c) enhancing support with learning assistants, and (d) linking calculus concepts to specific STEM careers, such as engineering, to better prepare students for their future professions. The great majority of the students in the courses (82%) are engineering majors, thus the impact of this reform is relevant for engineering educational experiences. The following are the specific research questions:

Research Questions:

1. What is the impact of engineering psychological factors (engineering self-efficacy, engineering identity, engineering sense of belonging) on 1st year Calculus performance in HSIs?
2. How does the impact of engineering psychological factors on 1st year Calculus performance change, if at all, when mathematics-specific psychological factors (math interest, self-concept and anxiety) are considered?
3. What is the impact of active engagement and classroom factors on 1st year Calculus performance?

Methodology

Participants

Students taking Calculus 1 and Calculus 2 courses in the spring semester were recruited to participate in the study for extra credit. The total sample for the spring semester was 805 students (467 from Calculus 1 and 338 from Calculus 2), 568 males, 225 females. The ethnicity and race distributions for the entire sample were as follows: 371 Latinx, 197 east Asian, 93 south Asian, 99 Euro-American and 35 African American. Of these, 433 were classified as underrepresented minorities in engineering and 373 were classified as first-generation college students. Students completed the measures using the Qualtrics online platform in the last two weeks of the course. Both the order of the measures and the items for each measure were randomly presented to students to control for order effects and response fatigue. The set of measures took approximately 55 minutes to complete.

Measures

The variables of interest included one exogenous variable, self-efficacy, three math-related endogenous variables (math interest, math self-concept, and math anxiety), one engagement variable (self-regulation), and two outcome variables (STEM identity and STEM sense of belonging). These measures targeting these variables are described next.

Engineering Self-Efficacy. Engineering self-efficacy is one dimensional construct comprised of nine items capturing confidence in one's ability to perform engineering-specific behaviors or accomplish an engineering-specific task [e.g., use technical stem skills (use tools, instruments, or techniques), use engineering literature and/or reports to guide research or the engineering design process]. Responses are rated on a 5-point Likert scale from 1 representing "strongly disagree" to 5 representing "strongly agree".

Mathematics Interest. Mathematics interest is a 22-item measure that targets individual interest related to mathematics-specific tasks involving four dimensions of interest: math emotions (e.g., I enjoy studying calculus), math values (e.g., I think calculus is helpful for my career), math knowledge (e.g., I have a lot of knowledge about calculus), and math engagement (e.g., I want to learn things that are not included in calculus textbooks). Responses are rated on a 5-point Likert scale from 1 representing "strongly disagree" to 5 representing "strongly agree".

Mathematics Self-Concept. Self-concept is defined as the personal perception that arises from the interactions with the context. The mathematics self-concept is a seven-item measure capturing ability beliefs in math general skills containing two dimensions: positive self-concept (e.g., I usually do well in math) and concerns about math (e.g., Math is harder for me than other courses). Responses are rated on a 5-point Likert scale from 1 representing "strongly disagree" to 5 representing "strongly agree".

Engineering Identity. STEM Identity refers to the extent to which the student identifies as a engineering professional. This measure is comprised of twelve items that target two dimensions: identity (in general, being a engineering professional is an important part of my selfimage) and commitment (e.g., I intend to work in job related to engineering). Responses are rated on a 5-point Likert scale from 1 representing "strongly disagree" to 5 representing "strongly agree".

Mathematics Anxiety. The mathematics anxiety measure is a six-item measure targeting the unpleasant affective experience that arises when confronted with mathematics. It is comprised of two dimensions: worry (e.g., Before taking a calculus test, I am worried about forgetting everything I learned) and performance (e.g., I get nervous when I ask something in the calculus class). Responses are rated on a 5-point Likert scale from 1 representing "not at all" to 5 representing "very much".

Engineering Sense-of-Belonging. Sense of belonging refers to the emotional need to affiliate with and be accepted by members of a engineering community. The seventeen-item measure is comprised of five dimensions: membership (e.g., I feel that I belong to this community), acceptance (e.g., I feel accepted.), affect (e.g., I feel at ease), fade (e.g., I wish I can fade into the background), and trust (e.g., I trust my instructors to be committed to helping me learn). Responses are rated on an 8-point Likert scale from 1 representing "strongly disagree" to 8 representing "strongly agree."

Analysis

Mixed effects Hierarchical Linear Model analyses were conducted to answer the research questions. Table 1 presents the level 1 and level 2 variables. Each of the level 1 predicter variables were group mean centered and each level 2 predictor variables were grand mean centered. To answer the research questions, six models were compared:

1. Model 1: (the baseline model): Level 1 indicators: **student background characteristics** (high school math GPA, gender, URM status, first gen status, and home income); Level 2 indicators: campus and course section
2. Model 2: (the **STEM psychological factors only** model): Level 1 indicators: **student background characteristics** (high school math GPA, gender, UMS status, first generation status, and home income); **+ STEM psychological factors** (engineering identity, Engineering sense of belonging and engineering self-efficacy): Level 2 indicators: discussion section
3. Model 3: (the **math psychological factors only** model): Level 1 indicators: student background model variables + engineering psychological factors **+ math psychological factors** (math interest, math self-concept and math anxiety): Level 2 indicators: discussion section
4. Model 4: (the **STEM + math psychological factors** model): Level 1 indicators: student background model variables + **STEM psychological** factors **+ math psychological factors** (math interest, math self-concept and math anxiety): Level 2 indicators: discussion section
5. Model 5: (the classroom factors model): Level 1 indicators: student background model variables + math interest + math self-concept: Level 2 indicators: discussion section **+ proportion Frist generation students + proportion URM + proportion female students**
6. Model 6: (the active engagement model): Level 1 indicators: student background model variables + math psychological factors: Level 2 indicators: discussion section **+ proportion first generation students + classroom active engagement**

Results

The Hierarchical Linear Modeling (HLM) analyses (Tables 2 and 3) investigated the impact of student background factors, STEM psychological factors, math-specific psychological factors, and classroom-level variables on calculus grades. The analysis revealed significant predictors at both the individual and classroom levels.

Individual Level Effects

Impact of student background factors. Consistent with past research, the baseline model (Model 1) shows that all Level 1 variables significantly predicted calculus grades. Males appeared to outperformed females when other factors were not considered in the model. This effect held after adding in the STEM psychological factors in Model 2, but not when math psychological factors were added to the model (Model's 3-5), suggesting that gender differences in calculus performance become much less decisive in explaining calculus grades compared to other variables. All other Level 1 variables remained significantly associated with calculus grades in all 6 of the models. The direction of the relationship between some of the background variables was not consistent with past research. Notably, underrepresented minority status (URMs) consistently impacted calculus grades (β ranged from -0.258 to -0.271, p's < .05) in an unexpected direction. Since belonging to a URM group was coded as 0 and non-URM as a 1, the negative association suggests that URM students, on average, receive higher calculus grades compared to their non-URM peers. This finding was consistent across all 6 models. URMs received a course grade about .26 higher course grade than their non-URM counterparts.

Table 1.

Descriptive Statistics (N = 789)

Variable	Mean	SD	Scale Range
Dependent Variable			

Calculus Grade	2.34 (C)	1.40	1-4.5
Level 1 Variables			
Student Background			
Gender	.28	.45	0=M; 1=F
Underrepresented Status	.51	.50	1=no; 0=yes
First-Gen Status	.47	.49	0=no;1=yes
Home Income	93,945.99	47,828.19	13,495 - 215,976
High School Math Grades	3.53	.49	1.5 - 4.7
Psychological Factors			
STEM Self-Efficacy	3.13	.73	1-5
STEM Identity	3.63	.84	1-5
STEM Sense of Belonging	5.07	1.24	1-8
Math Interest	3.31	.75	1-5
Math Self-Concept	3.36	.76	1-5
Math Anxiety	3.43	.96	1-5
Level 2 Variables			
Classroom Level Factors			
Proportion Female	.28	0.11	.08 -.55
Proportion First-Gen	.57	.15	.29 - .83
Proportion URMs	.54	.10	.35 - .74
Active Engagement	3.31	.88	1-5

Similarly, across all the models, first-generation college students showed significantly higher calculus grades ($\beta's$ ranged from about 0.60 to 0.62, p's < .001) than their non-first-generation students. Thus, on average, first generation students received .6 higher grade than students who were not first generation. Finally, high school math grades were significant predictors of first year calculus across all 6 models ($\beta's$ ranged from 0.52 to 0.69, p's < .001), suggesting that students with higher high school math grades received higher calculus grades.

Table 2.

Multilevel Model Comparisons for Predictors of Calculus Performance in First-Year Calculus Courses (N = 789)

	Model 1 Baseline: Background Variables Only		**Model 2: Background Variables + STEM Psych Factors**		**Model 3: Background Variables + Math Psych Factors**		**Model 4: Background + STEM Psych Factors + Math Psych Factors**		**Model 5: Background + Math Psych Factors + Class Level Factors**	
	Estimate	s.e.	Estimate	s.e.	Estimate	s.e.	Estimate	s.e.	Estimate	s.e.
Intercept	**2.308**	0.347	**2.308**	0.091	**2.308**	0.091	**2.307**	0.091	**2.305**	0,081
Student Background										
Fam. Income	**2.0^{-6}**	1.0^{-6}	**2.0^{-6}**	1.0^{-6}	**2.0^{-6}**	1.0^{-6}	**2.0^{-6}**	1.0^{-6}	**2.0^{-6}**	1.0^{-6}
Gender	**-0.252**	0.074	**-0.196**	0.082	-0.123	0.099	-0.121	0.087	-0.123	0.087
URMs	**-0.267**	0.098	**-0.271**	0.101	**-0.259**	0.092	**-0.258**	0.102	**-0.259**	0.104
First-Gen	**0.624**	0.106	**0.620**	0.108	**0.602**	0.094	**0.604**	0.102	**0.602**	0.102
HS Math Grade	**0.686**	0.077	**0.660**	0.075	**0.533**	0.094	**0.530**	0.084	**0.533**	0.083
STEM Psych Factors										
Sense of Belonging			**0.106**	0.037	—	—	-0.004	0.040	—	—
Identity			0.035	0.075	—	—	-0.042	0.082	—	—
Self-Efficacy			8.46-4	0.074	—	—	-0.067	0.076	—	—
Math Psych Factors										
Interest					**0.205**	0.066	**0.249**	0.099	**0.205**	0.078
Self-Concept					**0.169**	0.071	**0.178**	0.066	**0.169**	0.063
Anxiety					-0.065	0.049	-0.071	0.039	-0.065	0.040
Classroom Level										
Proportion Female									-0.064	0.786
Proportion First-Gen									**-1.50**	0.630
Proportion URMs									-0.256	0.916
Deviance Statistic	2593.78 (8)		2583.33 (11)		2559.38 (11)		2557.53 (14)		2551.53	

Note: Fam. = Family; URMs = Underrepresented Minoritized Student; Fem = Female; Psych = Psychological; number in parentheses reflects the estimated parameters.

Impact of psychological factors. STEM psychological factors were examined alone first. Model 2 adds STEM psychological factors (sense of belonging, identity, self-efficacy) to the analysis, with sense of belonging showing a significant positive effect on calculus grades (β = 0.106, p = 0.008). This positive coefficient indicates that an increase in a student's sense of belonging is associated with an improvement in their calculus grade. Specifically, for each one-unit increase in the sense of belonging scale, a student's calculus grade is expected to increase by 0.106, controlling for other factors in the model. The inclusion of psychological factors in Model 2 improves model fit, as indicated by a lower deviance statistic (2593.78 to 2583.33). This summary highlights the importance of both background characteristics and STEM psychological factors in understanding student performance in first-year calculus courses.

To answer the second research question, we first compared the STEM psychological factors only model (Model 2) with the math-specific psychological factors only model (Model 3). In terms of mathematics-specific psychological factors, math interest *(*β = 0.205, p =) and math self-concept *(*β = 0.169, p =) significantly predicted calculus grades. Math anxiety was negatively associated with course grades but not significant. Across the remining models, both math interest and math self-concept predicted calculus grades (*β's* ranged from 0.21 to 0.25 and 0.17 to 0.18 respectively for interest and self-concept). Anxiety remained a marginally significant predictor and accounted for much less of the overall variation in calculus grades. Sense of belonging was no longer significant after controlling for math psychological factors. In the final model, the positive estimates of math interest (β = 0.210, p = .007) and math self-concept (β = 0.179, p = .003) indicate that students who have a higher interest in math and a better self-concept of their math abilities than their classmates tend to perform better in calculus. Math anxiety was negatively associated with calculus grades, suggesting that students with more math anxiety than the average of their classmates tend to have lower calculus grades, though this relationship was not statistically significant (β = -0.073, p = .055). The non-significant impact of math anxiety, while negative, suggests that its effect might be nuanced or overshadowed by other the other predictors.

Classroom Level Effects

At the classroom level (Table 2, Models 5), we first examined three classroom level effects (proportion of female students, proportion of first-generation students and proportion of URMs in the discussion section) to identify those what would be used in the final model comparisons (Table 3). The proportion of first-generation students was the only class level factor related to average calculus grades (β = -1.52, p = 0.023), indicating that the classroom composition with more first-generation students than the average significantly differs from those in the average classroom, after accounting for other factors in the model. Discissions sections with higher proportions of first-generation students have 1.52 course grade lower than the average classrooms. Remarkably, the negative effect of first-generation student composition did not hold when active engagement was added to the model (Model 6) (β = -0.311, p = .405), indicating that the classroom composition in terms of first-generation college students does not impact the average calculus grades. However, active classroom engagement was positively associated with higher calculus grades (β = 0.948, $p < .001$), highlighting the importance of engagement in learning outcomes.

Impact of Active Engagement & Classroom Factors (Q3)

In the final model (Model 6) predicting first-year calculus performance, all student background variables remained significant and in the same direction, family income (β = 2.0^{-6}, p = .002), being a first-generation college student (β = 0.598, $p < .001$), and high school math GPA

Table 3.

Final Model Predictors of Calculus Performance in First-Year Calculus Courses (N = 789)

	Model 6			
	Estimate	s.e.	t-ratio	p
Intercept	2.320	0.052	44.797	< .001
Student Background				
Family Income	**2.0^{-6}**	1.0^{-6}	3.042	0.002
URMs	**-0.262**	0.103	-2.537	0.011
First-Gen	**0.598**	0.101	5.906	< .001
HS Math Grade	**0.519**	0.081	6.431	< .001
Math Psych Factors				
Interest	**0.210**	0.077	2.709	0.007
Self-Concept	**0.179**	0.061	2.949	0.003
Anxiety	-0.073	0.038	-1.922	0.055
Classroom Level				
Proportion First-Gen	-0.311	0.368	-0.843	0.405
Active Engagement	**0.948**	0.091	10.421	< .001
Random Effects	SD	Variance	χ^2	p
Residual	0.174	0.030	54.79	0.013
Deviance Statistic		2521.47		

(β = 0.519, p < .001) were significant predictors of calculus performance. For underrepresented minorities (URMs), the effect was significant (β = -0.262, p = .011). The patterns found in Model 5 pertaining to mathematical psychological factors, were also observed in Model 6 with both interest (β beta = 0.210, p = .007) and self-concept (β = 0.179, p = .003) remaining positively associated with calculus performance, and math anxiety was not a significant predictor (β = -0.073, p = .055).

At the classroom level, active engagement strategies were a strong positive predictor of student performance (β = 0.948, p < .001), while the proportion of first-generation students in a class did not significantly impact performance (β = -0.311, p = .405) as stated above. These results imply students in classrooms implementing active engagement strategies above the grand mean better calculus performance overall. Indeed, they have almost one letter grade higher than other classrooms. The nonsignificant effect for the proportion of first-generation students in a class suggests this factor does not distinguish classroom performance relative to the overall average when active engagement is integrated into classroom practice.

Discussion

The HLM analysis presented significant insights into the factors influencing calculus grades at both individual and classroom levels. This discussion will interpret these findings, explore their implications, and suggest directions for future research.

Individual Level Effects

The analysis confirmed that student background factors, such as gender, underrepresented minority status (URMs), first-generation college status, and high school math grades, significantly predict calculus performance. Interestingly, gender differences were mitigated upon the introduction of math-specific psychological factors, indicating these factors play a critical role in explaining calculus grades beyond mere demographic characteristics. The unexpected positive performance of URMs and first-generation college students challenges conventional narratives and suggests the presence of resilience factors or differential educational pathways that merit further investigation.

In this regard, the reduction of gender disparities when math-specific psychological factors are taken into account underscores the significance of targeted interventions designed to cultivate a positive math identity and enthusiasm for mathematics across all genders. This approach aligns with Bandura's theory, suggesting that belief in one's capabilities plays a pivotal role in motivational processes [1,2]. Additionally, the application of Eccles and Wigfield's expectancy-value model within our interventions, which posits that achievement-related choices are influenced by the expectation of success and the value of the task [3], provides a theoretical basis for understanding the improvements in calculus grades. This supports the claim that the resilience demonstrated by URMs and first-generation students might be linked to a range of support mechanisms. Some of these are integral components of the intervention, such as peer mentoring, while others may be ingrained within the culture of HSIs, including community-building initiatives that underscore the importance of persistence and self-efficacy in navigating academic hurdles.

The positive impact of psychological factors, including a sense of belonging, math interest, and self-concept, on calculus grades underscores the importance of addressing students' affective and motivational dimensions. These findings align with the literature emphasizing the role of psychological well-being in academic success and suggest that interventions aimed at enhancing these psychological assets could improve performance [3,4].

Classroom Level Effects

At the classroom level, the composition in terms of the proportion of first-generation students initially appeared to negatively impact average calculus grades. However, this effect was mitigated by active engagement strategies, highlighting the transformative potential of pedagogical approaches that foster engagement. This pattern suggests that active learning environments may override the disadvantages associated with demographic factors, demonstrating the importance of inclusive teaching strategies that cater to diverse student populations.

Implications for Educational Practice

The findings suggest several actionable insights for educators, administrators, and policymakers aimed at enhancing calculus achievement among engineering majors, particularly for underrepresented and first-generation college students. Firstly, the importance of psychological factors in mathematics achievement calls for the integration of support mechanisms that foster a positive self-concept and interest in mathematics. Curriculum designers and educators may consider developing instructional materials and pedagogical strategies that bolster math interest and self-concept for all students. Programs designed to enhance math interest could include integrating real-world problems that are relevant to the students' lives and future engineering practices, thus making the learning experience more engaging and meaningful. Similarly, initiatives aimed at improving math self-concept might involve creating a classroom environment that encourages growth mindset, emphasizes effort over innate ability, and provides regular, constructive feedback [1, 3].

Secondly, the effectiveness of active engagement strategies in mitigating the negative effects of certain classroom compositions indicates that such pedagogical approaches should be promoted and further researched. These efforts should culminate in faculty development programs that equip instructors with the skills to implement active learning practices in their classrooms. Such evidence-based training requires a range of methodologies, from problem-based learning to the use of technology for interactive simulations, with a focus on adapting these strategies to support diverse learning needs and backgrounds [38, 39]. Moreover, this requires institutional support for smaller class sizes, reconfiguration of physical learning spaces to facilitate group work, and allocation of resources to implement active learning initiatives.

Although these suggestions appear to target individual and classroom-level factors separately, it is crucial to recognize the interconnected nature of these elements. The current findings suggest that self-efficacy operates not merely as a predictor of academic success but potentially also serves as a mediator between engagement strategies and academic performance.

This observation is consistent with existing literature which posits that active engagement in learning environments can significantly bolster self-efficacy, thereby creating a virtuous cycle that positively influences academic achievement [26]. Thus, the strategic integration of active learning methodologies in calculus classrooms could yield dual benefits: directly enhancing academic outcomes and indirectly fostering a robust sense of self-efficacy among students. This dual impact hints at the transformative potential of active learning, not only in terms of immediate academic performance but also in its potential for cultivating enduring psychological assets that contribute to sustained academic and professional success.

Future Research Directions

Future studies should explore the mechanisms through which psychological factors and active engagement strategies exert their effects, potentially identifying target areas for intervention. A detailed analysis of which specific aspects of active engagement are most effective in enhancing calculus performance and fostering positive psychological assets is needed. Research should aim to identify and categorize the various active learning strategies employed in calculus classrooms, assessing their prevalence and effectiveness. This could involve observational studies, instructor surveys, and student feedback to determine what proportion of class time is dedicated to different active learning techniques and how this correlates with student outcomes. To complement the analysis of active engagement components, research should also examine the rate at which these strategies are implemented across different institutions, departments, and individual classrooms. Identifying factors that facilitate or hinder the adoption of active learning strategies can inform efforts to promote broader implementation. This research direction could explore institutional policies, instructor beliefs and attitudes towards active learning, and the availability of resources and training for educators.

Additionally, the unique experiences and strengths of URMs and first-generation college students warrant further qualitative and quantitative investigation to understand the factors contributing to their success. There is also a need to investigate the longevity of the positive impacts of calculus interventions on psychological factors such as self-efficacy, math interest, and self-concept. A longitudinal study could follow participants over multiple semesters or years to assess how long the benefits of interventions last without reinforcement versus with periodic reinforcement in subsequent math classes. This research could extend to examining whether initial improvements in calculus performance and psychological assets translate into sustained academic success and higher STEM retention rates. This could involve tracking students who received interventions to see if there are higher rates of persistence and completion in STEM degree programs compared to those who did not participate in such interventions. Analyzing these outcomes can help educators and policymakers identify effective strategies that supports all students, but also helps to address the performance gap associated with underrepresented groups in STEM fields,

Conclusion

This study contributes to a nuanced understanding of the multifaceted factors influencing calculus performance among engineering majors. Overall, the HLM analyses suggest that both individual background factors and psychological attitudes towards math, as well as the level of active engagement in the classroom, are important determinants of students' calculus grades. The findings highlight the complexity of factors influencing academic performance in calculus and underscore the need for targeted interventions to support students from underrepresented groups and to foster a positive math self-concept and interest among all students. By highlighting the significant role of psychological and classroom-level factors, it provides a foundation for developing more equitable and effective educational practices.

References

[1] Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review, 84(2)*, 191-215.

[2] Bandura, A. (1997). Self-efficacy: The exercise of control. New York: W.H. Freeman.

[3] Eccles, J. S., & Wigfield, A. (2002). Motivational beliefs, values, and goals. *Annual Review of Psychology, 53(1)*, 109-132.

[4] Hackett, G. (1995). Self-efficacy in career choice and development. In A. Bandura (Ed.), *Self-efficacy in changing societies* (pp. 232-258). New York: Cambridge.

[5] Rottinghaus, P. J., Larson, I. M., Borgen, F. H. (2003). The relation of self-efficacy and interests: A meta-analysis of 60 samples. *Journal of Vocational Behavior, 62,* 221-236.

[6] Hidi, S., & Renninger, K. A. (2006a). The role of interest in learning and development. *Annual Review of Psychology, 57(1)*, 517-540.

[7] Hakkarainen, K., & Malmberg, J. (2004). *Communities of networked expertise: Professional and educational perspectives.* Berlin: Springer.

[8] Hidi, S., & Renninger, K. A. (2006b). The four-phase model of interest development. *Educational Psychologist, 41(2)*, 111-127.

[9] Authors (2021) Blinded for review

[10] Crouch, C. H., Wisittanawat, P., Cai, M., & Renninger, K. A. (2018). Life science students' attitudes, interest, and performance in introductory physics for life sciences: An exploratory study. *Physical Review Physics Education Research 14*, 010111.

[11] Azevedo, F. S. (2013) The Tailored Practice of Hobbies and Its Implication for the Design of Interest-Driven Learning Environments, *Journal of the Learning Sciences, 22(3)*, 462-510. DOI: 10.1080/10508406.2012.730082

[12] Renninger, K. A., & Hidi, S. E. (2019). Interest development and learning. In K. A. Renninger & S. E. Hidi (Eds.), *The Cambridge handbook of motivation and learning* (pp. 265–290). Cambridge University Press. https://doi.org/10.1017/9781316823279.013

[13] Shavelson, R. J., & Stern, P. (1981). Research on teachers' pedagogical thoughts, judgments, decisions, and behavior. *Review of Educational Research, 51*(4), 455–498. https://doi.org/10.2307/1170362

[14] Marsh, H. W., & Martin, A. J. (2011). Academic self-concept and academic achievement: Relations and causal ordering. *British Journal of Educational Psychology, 81(2)*, 301-321.

[15] Jansen, P., Schroeders, U., & Lüdtke, O. (2014). Self-concept and subject-specific achievement: Longitudinal reciprocal relationships and the role of affective and cognitive aspects. *Journal of Educational Psychology, 106(1)*, 97-111.

[16] Denissen, J. J., Zarrett, N. R., & Eccles, J. S. (2007). I like to Do It, I'm Able, and I Know I Am: Longitudinal Couplings between Domain-Specific Achievement, Self-Concept, and Interest. *Child Development , 78(2),* 430-447.

[17] Cokley, K. O., Bernard, N., Cunningham, D., & Motoike, J. (2012). A psychometric investigation of the academic self-concept of African American college students. *Journal of Black Psychology, 38(3),* 281-301.

[18] Wang, M. T., & Degol, J. L. (2014). Motivational pathways to STEM career choices: Using expectancy–value perspective to understand individual and gender differences in STEM fields. *Developmental Review, 34(4)*, 340-363.

[19] Zeidner, M. (2014). Anxiety in education. In R. Pekrun, & L. Linnembrink-García (Eds.), *International handbook of emotions in education* (pp. 265–288). New York: Routledge.

[20] Pekrun, R., & Perry, R. (2014). Control-value theory of achievement emotions. In R. Pekrun, & L. Linnembrink-García (Eds.), *International handbook of emotions in education* (pp. 120–141). New York: Routledge.

[21] Núñez-Peña, M., Suárez-Pellicioni, M., Guilera, G., & Mercadé-Carranza, C. (2013d). A Spanish version of the short Mathematics Anxiety Scale (sMARS). *Learning and Individual Differences, 24*, 204–210. http://dx.doi.org/10.1016/j.lindif.2012.12.009.

[22] Steinmayr, R., Wirthwein, L., & Schöne, C. (2014). Gender and numerical intelligence: Does motivation matter? Learning and Individual Differences, 32, 140–147. http://dx. doi.org/10.1016/j.lindif.2014.01.001.

[23] González, A., Rodríguez, Y., Faílde, M., & Carrera, M. V. (2016). Anxiety in statistics class: structural relations with self-concept, intrinsic value, and engagement in two samples of undergraduates. *Learning and Individual Differences, 45*, 214-221.

[24] Sinatra, G., Broughton, S., & Lombardi, D. (2014). Emotions in science education. In R. Pekrun, & L. Linnembrink-García (Eds.), *International handbook of emotions in education* (pp. 415–436). New York: Routledge.

[25] Kesici, S., Baloğlu, M., & Deniz, M. (2011). Self-regulated learning strategies in relation with statistics anxiety. Learning and Individual Differences, 21, 472–477. http://dx.doi.org/10.1016/j.lindif.2011.02.006.

[26] Zimmerman, B. J. (2000). Self-efficacy: An essential motive to learn. *Contemporary Educational Psychology, 25*, 82–91.

[27] Graham, S., & Harris, K. R. (2000). The role of self-regulation and the development of literacy and numeracy skills: Results from a longitudinal study. *Merrill-Palmer Quarterly, 46(3),* 203-224.

[28] Fredricks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School engagement: Potential of the concept, state of the evidence. *Review of Educational Research, 74(1),* 59-109.

[29] Good, C., Aronson, J., & Inzlicht, M. (2003). Improving adolescents' standardized test performance: An intervention to reduce the effects of stereotype threat. *Journal of Applied Developmental Psychology, 24(6)*, 645-662.

[30] Lent, R. W., Brown, S. D., & Larkin, K. C. (2000). The relation of social support to the career development of women and minorities: A test of social cognitive career theory. *Journal of Career Assessment, 8(2)*, 127-143.

[31] Eccles, J. S., Wigfield, A., Harold, R. D., & Blumenfeld, P. C. (1993). Age and developmental differences in children's self- and task-perceptions during early adolescence. *Child Development, 64(3),* 830-847.

[32] Gupta, D., Eccles, J. S., & Singh, K. (2015). Longitudinal effects of multiple sources of self-esteem on African American and European American adolescents' academic and behavioral outcomes: A comparison of self-esteem theory and social identity theory. *Journal of Youth and Adolescence, 44(6),* 1164-1179.

[33] Kleitman, D. (2009). Calculus for Beginners and Artists, MIT.

[34] Bong, M. (2001). Between- and within-domain relations of academic motivation among middle and high school students: Self-efficacy, task value, and achievement goals. *Journal of Educational Psychology, 93*, 23-34.

[35] Pajares, R. (1996). Self-efficacy beliefs in academic settings. *Review of Educational Research, 66*, 543-578.

[36] Wigfield, A. & Eccles, J. S. (1994). Childrens's competence beliefs, achievement values, and general self-esteem change across elementary and middle school. *Journal of Early Adolescence, 14,* 107-138.

[37] Bong, M., Lee, S. K., & Woo, Y. (2015). The roles of interest and self-efficacy in the decision to pursue mathematics and science. In K. A. Renniger, M. Nieswantd, & S. Hidi (2015). *Interest in mathematics and science learning,* pp. 33-48. Washington, DC: American Educational Research Association.

[38] Stanberry, M. L. (2018) Active learning: a case study of student engagement in college Calculus, *International Journal of Mathematical Education in Science and Technology, 49*:6, 959-969, DOI: 10.1080/0020739X.2018.1440328

[39] Freeman S, Eddy S, McDonough M, et al. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proc Natl Acad Sci, 111(23)*, 8410–8415.

[40] Ding, N., Bosker, R.J., & Harskamp, E.G. (2011). Exploring gender and gender pairing in the knowledge elaboration processes of students using computer-supported collaborative learning. *Computers & Education, 56*, 325-336.

[41] Khalid, M. S., Zhanyong, Q., & Bibi, j. (2021) The impact of learning in a diversified environment: social and cognitive development of international students for global mind-set. *European Journal of Training and Development, 46 (5/6),* 373-389 DOI 10.1108/EJTD-12-2020-0175;

[42] Sciffer, M.G., Perry, L.B., & McConney, A. (2022). The substantiveness of socioeconomic school compositional effects in Australia: measurement error and the relationship with academic composition. *Large-scale Assess Educ* 10-22. https://doi.org/10.1186/s40536-022-00142-8