Structural Equation Model of Causal Factors Affecting Achievement in Calculus 1 for Engineering and Architecture Students

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Abstract
This research aimed to develop and validate a structural equation model of causal factors influencing achievement in Calculus 1 for students in the Faculty of Engineering and Architecture. The sample consisted of 375 first-year students, obtained through stratified random sampling. Research instruments included questionnaires and an achievement test. Data were analyzed using Structural Equation Modeling (SEM). Results showed that the developed model was consistent with empirical data ($\chi 2=6.45$, df=5, p=0.07, RMSEA=0.038, CFI=0.95, GFI=1.00, AGFI=0.99). Factors directly influencing achievement in Calculus 1 were mathematical aptitude ($\beta=0.07$), achievement motivation ($\beta=0.20$), mathematical background knowledge ($\beta=0.18$), attitude towards calculus ($\beta=0.25$), and learning behavior ($\beta=0.28$). Achievement motivation and attitude towards calculus also indirectly affected achievement in Calculus 1 through learning behavior. This model explained 75.51% of the variance in achievement in Calculus 1. The results show a need to cultivate mathematical aptitude, improve motivation, and bridge mathematical background knowledge to facilitate achievement in Calculus 1. They also stress the influence of attitudes and achievement motivation on developing suitable learning habits. The results can be utilized to instruct pedagogical techniques and prepare students in engineering and architecture training programs to increase their learning performance in Calculus 1 courses.

Keywords: Academic Achievement, Calculus1, Structural Equation Model (SEM)

Introduction

One of the fundamental equations that form the foundation of engineering and scientific education. The foundation of logical abilities is mathematics. Calculus, for instance, is an essential subject in engineering and architecture courses to grasp better the increasingly complex mathematical models used to explain physical systems, design processes, and architectural phenomena (Stewart, 2015). However, further advanced courses in engineering and architecture institutions usually require Calculus 1, which may contain limits, derivatives, and integrals. However, despite its importance, Calculus 1 remains a significant challenge for many students (Thomas et al., 2016). Calculus 1 is required for most engineering and architectural schools, and because of the subjects it covers (such as limits, derivatives, and integrals), it is frequently a prerequisite for more complex courses. Therefore, understanding the fundamental elements influencing students' success in this important subject is essential for educators and policymakers in various professions (Black & Smith, 2018).

Calculus learning is influenced by many factors, especially for first-year students in challenging majors like engineering and architecture (Zhu & Simon, 2020). Intrinsic elements like motivation, cognitive capacity, and prior mathematics knowledge are also crucial, even though extrinsic factors like the classroom atmosphere, instructional strategies, and resources available greatly influence student success (Barkley & Howell, 2017). In addition, students' attitudes toward the subject, their study habits, and their level of effort are other intrinsic factors that may impact their performance in mathematics (Boekaerts, 2011). Researchers have turned to structural equation modeling (SEM) to identify and quantify these effects systematically, a powerful technique for understanding the complex relationships between variables affecting student performance. This statistical approach provides a comprehensive grasp of how different internal and external factors interact to affect student success in a subject as complicated as calculus (Wang & Liu, 2019).

Numerous important elements have been shown to influence students' performance in university-level calculus, with particular attention paid to emotive, cognitive, and prior mathematical knowledge. One of the most important indicators of performance in college-level calculus courses is prior mathematical knowledge (Mason & Spence, 2014). According to Larsen (2013), students with a solid foundation in algebra and pre-calculus before starting college are usually better equipped to handle the more complex and abstract ideas covered in introductory calculus courses. However, past knowledge is not the only factor determining achievement; emotive and cognitive aspects are also important. Students' comprehension of calculus is also greatly aided by cognitive elements like spatial reasoning, logical reasoning, and the capacity to conceptualize mathematical ideas (Smith & Tisdale, 2017)—one of the fundamental equations at the basis of scientific and engineering education. Logical capabilities are based on mathematics. Calculus, for example, is a crucial subject in engineering and architecture courses to help students better understand increasingly intricate mathematical models that are used to explain physical systems, design procedures, and architectural phenomena (Stewart, 2015). Even so, calculus 1, which might include limits, derivatives, and integrals, is frequently required for later advanced courses in engineering and architectural schools. However, despite its significance, many students still struggle significantly with Calculus 1 (Thomas et al., 2016).

In addition to these individual-level components, children's achievement in calculus is influenced by other classroom-level and institutional factors. One key issue is the quality of the instruction; students do better when they receive instruction from teachers who use active learning tactics, provide brief explanations, and build a joyful but secure co-learning culture in the classroom (Freeman et al., 2014). Positive results can also be ascribed to the availability of academic aid services, such as online learning platforms, peer study groups, and tutoring centers (Yusuf et al., 2020). Therefore, a greater context should be considered when teaching calculus and how it relates to students' performance. Instruction calculus presented unique difficulties for working students pursuing careers in engineering or architecture. They already have to acquire calculus abstract ideas and apply them to solve practical engineering design or architectural planning challenges because their degrees are application-oriented (Cowan, 2016). These two expectations may be an additional cognitive load for students, particularly those who struggle with abstract mathematical reasoning or mathematical theory issues (Park & Kim, 2018).

Courses in architecture and engineering are also quite time-consuming and prescriptive. As a result, students are left with limited time after understanding challenging concepts like calculus. Many students enrolled in Calculus I have high-stress levels, which can further hinder their success (Jones & Redd, 2021). The intricacy of these interrelated effects greatly determines the requirement for a thorough model to capture interactions between variables affecting calculus students' achievement.

SEM is a highly desirable approach because, unlike more traditional regression models, it can estimate the direct and indirect associations between all variables, whether observed or unobserved, considering the latter as latent constructs that influence the dependent variable of interest (Byrne, 2016). When applied to the study of calculus achievement in engineering and architecture students, it becomes clear which factors are most important for achieving success in the subject and how these factors further interact to shape the student's performance. Additionally, SEM may be able to uncover the underlying mechanisms through which various variables impact calculus achievement, which would provide helpful information for designing targeted interventions to improve student outcomes (Jöreskog & Sörbom, 2017).

The current research creates a structural equation model on the elements that cause engineering and architecture students to achieve Calculus 1. The primary correlations to be highlighted are prior mathematical knowledge, cognitive and affective characteristics, and contextual factors, including academic assistance and instructional quality (Zhang et al., 2018). Therefore, it is reasonable to assume that this will help better understand the issues and difficulties faced by the students in these programs and result in more evidence-based suggestions for teaching and learning calculus courses.

Review of Literature and Related Research

Numerous studies have examined the factors influencing students' performance in challenging courses, such as Calculus 1 for engineering and architecture students. According to Mason and Spence (2014), the most significant direct influences include mathematical aptitude, drive for success, prior mathematical knowledge, calculus mindset, and learning style. Because they find it simpler to understand abstract concepts, students classified as mathematically gifted—including advanced problem-solving, logical reasoning, and spatial ability—frequently perform higher on calculus tests (Smith & Tisdale, 2017). Similarly, prior mathematical knowledge or readiness from previous math classes significantly influences students' achievement (Larsen, 2013).

Motivation related to achievement is needed to become successful in the field of academia, and it has a direct impact on calculus performance. Studies show that the high internal motivation of students is related to working through challenging problems and higher rates of attaining learning outcomes (Boekaerts, 2011). Another factor is the attitude towards calculus, which plays a significant role in enhancing performance. "Students who like mathematics or have confidence in their ability to do well in calculus experience less anxiety and do better" (Schoenfeld, 2019).

In addition to directly influencing calculus achievement, both achievement motivation and attitude toward calculus also indirectly affect calculus achievement through the intervening variable of the learning behavior. Students who are motivated and have positive attitudes are far more likely to engage in practical learning behaviors, such as studying regularly, taking an active role in the course material, and so forth, which lead to excellent performance (Freeman et al., 2014). Deriving motivation, positive attitudes and beliefs are important for better learning strategies and academic success in calculus, as seen from the relationship above. On top of these ways of thinking, cognitive and emotional factors that affect how well you do in calculus are also important. This suggests that you might need more than one way to help you do better in calculus.

Hypotheses Formulation

H1: Mathematical background knowledge (MB) would positively and directly affect the achievement in Calculus 1 (AC)
H2: Achievement motivation (AM) would positively and directly affect the achievement in Calculus 1 (AC)
H3: Attitude towards calculus (AT) would positively and directly affect the achievement in Calculus 1 (AC)
H4: Mathematical aptitude (MA) would positively and directly affect the achievement in Calculus 1 (AC)
H5: Learning behavior (LB) would positively and directly affect the achievement in Calculus1 (AC)
H6: Achievement motivation (AM) would positively and indirectly affect achievement in Calculus 1 (AC) through learning behavior (LB).
H7: Attitude towards calculus (AT) would positively and indirectly affect achievement in Calculus 1 (AC) through learning behavior (LB).

Conceptual Model of the Study

The conceptual model of this study was prepared using concepts from the theoretical and empirical literature. It is presented in Figure 1.

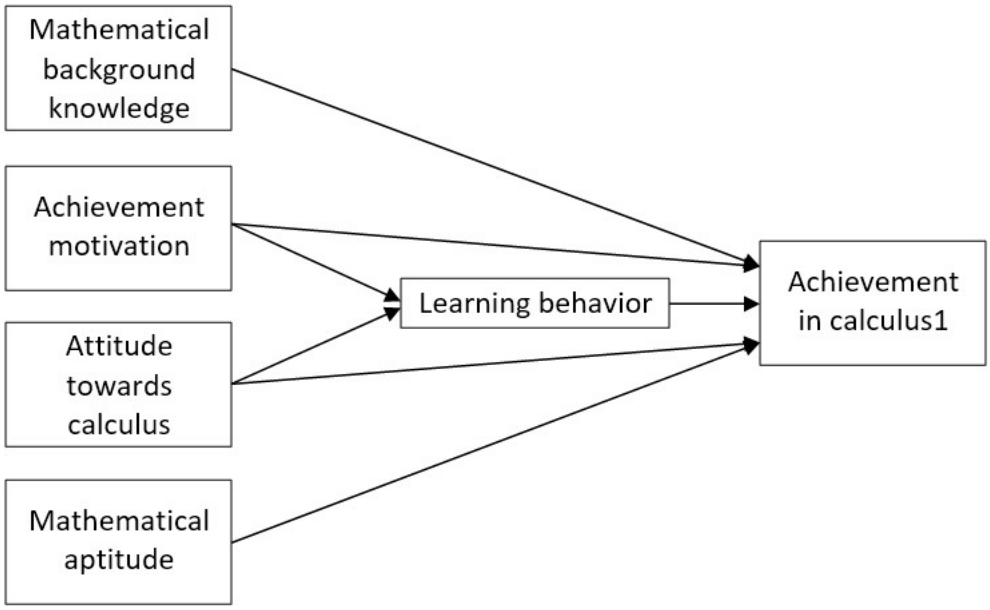

Figure 1: Proposed Theoretical Model

Research Methodology

Participant

The study participants were undergraduate students enrolled in a Calculus 1 course. They completed an online questionnaire covering Achievement Motivation (AM), Mathematical Background Knowledge (MB), Attitude Towards Calculus (AT), Learning Behavior (LB), and a Mathematical Aptitude (MA) test. Three hundred seventy-five participants were from the Faculty of Engineering and Architecture at Rajamangala University of Technology Suvarnabhumi. Among them, 312 were male (83.20%), and 105 were female (16.80%), with an average age ranging from 18 to 21.

Measurement

The questionnaire with a 5-point Likert scale measured Achievement motivation (AM), mathematical background knowledge (MB), attitude towards calculus (AT), and learning behavior (LB) variables.

The AM questionnaire included 10 items designed based on the four stages of AM: intrinsic motivation, extrinsic motivation, goal orientation, and persistence (Ryan & Deci, 2000).

The MB questionnaire included 10 items designed based on the four stages of MB: ability to solve algebraic equations, analysis and interpretation of graphs, understanding of functions, and basic knowledge of geometry (Allen, 2001).

The AT questionnaire included 10 items designed based on the five stages of AT: enjoyment, anxiety, perceived usefulness, and confidence in Calculus 1 (Wong & Chen, 2012).

The LB questionnaire included 10 items designed based on the four stages of LB: study habits, participation in class, self-regulation, and motivation (Zimmerman, 2002).

The MA questionnaire included 12 items designed based on the four stages of MA: numerical reasoning, algebra, geometry, and applied problem-solving (Usher & Pajares, 2009).

Achievement in Calculus 1 (AC) was measured by the value of academic achievement in Calculus 1, which was measured by the final value of the Calculus 1 score at the end of the semester.

Data Collection

An online survey administered in August 2024 was used to gather data. At that time, adequate data for analysis was considered. Potential participants were provided with links to the online questionnaire with their instructors' consent.

Validity and Reliability Instruments

30 participants' data were used for pilot testing for the MB, AM, AT, MA, and LB instruments. According to the results, Cronbach's alpha coefficients for dependability were 0.81, 0.82, 0.81, 0.83, and 0.80, respectively.

Statistical Analysis

To evaluate the present investigation, a structural equation model (SEM) was utilized, adhering to known best practices that advocate for a sample size of no less than 100–200 (5–10 observations per parameter estimate) (Kline, 2011). For Structural Equation Modeling (SEM), an adequate sample size is a minimum of 200 to 300 respondents who have completed the questionnaire (Muthén et al., 1997); thus, the total sample of 375 students is deemed appropriate. The studies used Jamovi v. 2.4.8 (The Jamovi Project, 2023) to assess descriptive statistics, correlation, and path analysis for model fit evaluation.

Results

The descriptive statistics, which include the means, standard deviations, correlations, and Cronbach alpha coefficients, are presented in Table 1. Prior to analyzing the data, the researchers made sure to make the necessary assumptions for path analysis. Satisfied. The sample consisted of 375 participants. Table 1 displays descriptive statistics, including the means, standard deviations, correlations, and All variables have Cronbach's alpha coefficients. Before conducting data Using a path analysis, the researchers tested the assumptions that were met. The researchers selected 375 subjects from the pool.

The Shapiro-Wilk test validated the regular distribution by the skewness and kurtosis values. Variables. Moreover, the means ranged from 4.57 to 62.30, and the standard deviations (SD) from 0.48 to 11.19. P was less than. All variables were significantly correlated (*$p<.05$), and Cronbach's alphas were more than 0.70 for all variables, reflecting their high reliability.

Table 1: Correlation Coefficients and Descriptive Statistics

Factors	Mean	SD	Skewness	Kurtosis	Cronbach alpha	MB	AM	AT	MA	LB	AC
1. MB	4.58	0.48	-1.15	0.63	0.81	1.00					
2.AM	4.59	0.49	-1.29	0.64	0.82	0.72*	1.00				
3. AT	4.57	0.47	-1.23	0.59	0.81	0.76*	0.75*	1.00			
4. MA	4.57	0.58	-1.49	0.53	0.83	0.57*	0.57*	0.54*	1.00		
5. LB	4.58	0.48	-1.30	0.82	0.80	0.77*	0.82*	0.82*	0.51*	1.00	
6. AC	62.30	11.19	-0.04	-0.51	-	0.76*	0.78*	0.80*	0.56*	0.82*	1.00

The obtained model fit indices, presented in Table 2, such as $\chi2$=6.45, df=5, $\chi2$/df=1.29, p=0.07, RMSEA=0.04, CFI=0.95, GFI=1.00, AGFI=0.99 demonstrated that the structural model adequately fit the data sets.

Table 2: Evaluation of Model Fit Indices

Fit index	**Acceptable**	**Model Value (standard)**	**Fit**	**Resource**
$\chi2$/df	$0\leq\chi2/df\leq3$	1.29	Perfect	Kline (2011)
RMSEA	$0\leq RMSEA\leq0.08$	0.04	Perfect	Hooper et al. (2008)
CFI	$0.90\leq CFI\leq1$	0.95	Perfect	Tabachnick and Fidell (2007)
GFI	$0.90\leq GFI\leq1$	1.00	Perfect	Hair et al. (2006)
AGFI	$0.80\leq AGFI\leq1$	0.99	Perfect	Marsh et al. (1988)

The results of the path coefficients, presented in Table 3 and Figure 2, showed that MB (β=0.18, t value 4.15, p<0.001), AM (β=0.20, t value 4.01, p<0.001), AT (β=0.25, t value=4.82, p<0.001), MA (β=0.07, t value=2.24, p<0.025), and LB (β=0.28, t value=5.34, p<0.001) had significant positive direct effects on AC. Additionally, AM (β=0.13, t value=4.89, p<0.001) and AT (β=0.14, t value=4.91, p<0.001) had significant positive indirect effects on AC through LB. This model explained 75.51% of the variance in achievement in Calculus 1.

Table 3: Proposed Testing Results

Path	**Path coefficient**	**SE**	**t-value**	**P**	**Results**
AC←MB	0.18	0.04	4.15	< 0.001	Supported
AC←AM	0.20	0.05	4.01	< 0.001	Supported
AC←AT	0.25	0.05	4.82	< 0.001	Supported
AC←MA	0.07	0.03	2.24	0.025	Supported
AC←LB	0.28	0.05	5.34	< 0.001	Supported
AC←LB←AM	0.13	0.02	4.89	< 0.001	Supported
AC←LB←AT	0.14	0.03	4.91	<0.001	Supported

R^2=0.7551

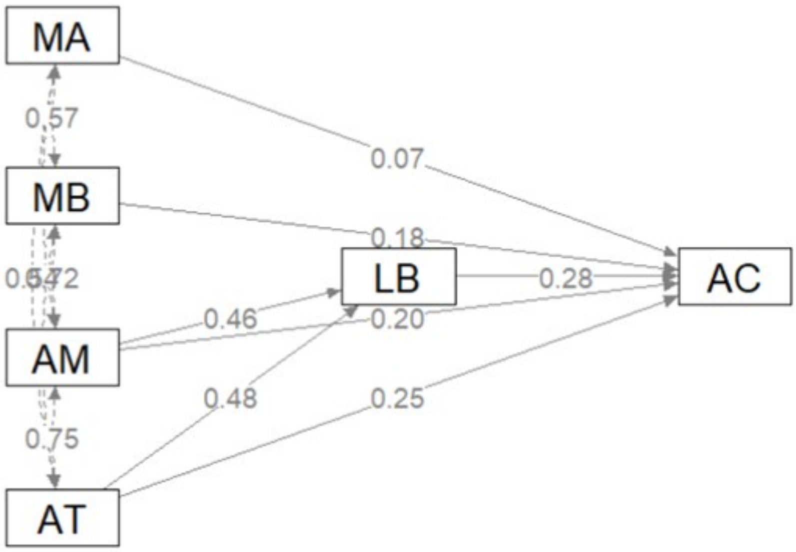

Figure 2: Results of Path Coefficients of the Research Model

Conclusion

Achievement in Calculus 1 (AC), a strong mathematical foundation, positively correlates with success in Calculus 1. This finding aligns with earlier research that showed that doing more complex tasks requires a strong foundation in the math needed (Usher & Pajares, 2008). Instead, it would be most advantageous for educators to utilize their time to strengthen the fundamental skills that prepare students for success.

Above all, the degree to which achievement motivation (AM) influences achievement in Calculus 1 (AC) demonstrates the impact of internal inspiration on academic performance. Motivated students perform better because they are more invested in the class and will find ways to work through obstacles (Deci & Ryan, 2000). This implies that fostering an inspiring learning environment could enhance Calculus 1 performance.

Finally, there is a strong relationship between students' attitudes toward calculus (AT) and achievement in Calculus 1 (AC), showing that how students feel about the subject affects how well they perform. Researchers commonly link the anticipation of success (a favorable attitude toward calculus) to the application of greater effort to succeed (Pajares & Kranzler, 1995). Such projects designed to encourage a positive mindset in math could be helpful, especially for struggling children.

The strong link between mathematical aptitude (MA) and success in Calculus 1 is another sign of how important it is to have hidden musical skills. According to Roberts et al. (2019), while it is possible to develop the skill, not every student pursues math. Each student could have thrived and succeeded with tailored instruction tapping their strengths.

The most substantial connection that can be made in Calculus 1 (AC) is to learning behavior (LB), which means that study habits, engagement, and other factors are more important for "studying" or doing well in school. Students using active studying techniques usually get more from their education (Pintrich, 2000). Educators here focus primarily on teaching effective learning strategies and helping students acquire these habits.

These results show that achievement motivation (AM) and attitudes toward calculus (AT) have positive indirect effects on students' performance in Calculus 1 (AC) through their learning behavior (LB). They also show that achievement motivation (AM) and attitudes toward calculus (AT) have positive direct effects on students' learning behavior (LB), which suggests that AM and AT are linked to academic success in some way, possibly through how they learn. This illustrates the intricate intertwining of multiple components (Schunk et al., 2008). According to Papanakou et al. (2021), positive attitudes and motivation lead to positive learning behaviors. When charting the way of doing and learning, education must ensure a conducive environment to motivate the students in the learning process; therefore, technology-enabled teaching must ensure a conducive environment.

Implication

These statistics indicate that achievement in Calculus 1 depends on several factors. An integrated approach may improve the comprehension of higher mathematics. These results further denote the connections between positive attitude, motivation, and learning the skills of calculus and their performance improvement. Timely intervention for students struggling with mathematics and teaching approaches featuring real-life applications and professional relevance could be key to turning things around. We hope educational policymakers, institutional administrators, and educators use these insights to inform curriculum design, teaching practices, and student support systems to improve calculus performance and build continued interest in STEM careers. By employing this holistic approach, which addresses cognitive, emotional, and behavioral domains, we may enhance calculus education and, by extension, all technical fields.

Limitation

Although it was adjusted for several relevant factors, many other important potential predictors may not have been measured. Factors like teaching quality, peer influences, or socioeconomic status, for example, could also play an important role in calculus achievement.

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