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Learning Analytics and Academic Efficiency in STEM Algebra Courses: Predictive Indicators from ALEKS Adaptive Data

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Abstract*– Foundational mathematics courses represent a critical point for student persistence and success in STEM programs. However, debate remains regarding which usage indicators in digital learning environments most accurately explain academic performance. The present study examined the differential impact of time on platform and adaptive practice volume on performance in an Algebra I course among engineering students. A dataset of 567 students from the ALEKS adaptive learning system was analyzed using Pearson correlations, multiple linear regression, and binomial logistic regression. Results showed that the number of adaptive exercises completed was the strongest predictor of academic performance, explaining, together with time on platform, 50.2% of the variance in achievement. In contrast, accumulated time on platform demonstrated a substantially smaller effect. Furthermore, each additional exercise reduced the probability of low academic performance by approximately 5%. These findings empirically distinguish between passive exposure and active engagement, providing relevant evidence for instructional design, learning analytics, and retention strategies in engineering education. Adaptive practice emerges as a strategic component for strengthening performance in foundational STEM mathematics courses.

***Keywords*-- adaptive learning; learning analytics; STEM education; engineering retention; deliberate practice; academic performance prediction.**

INTRODUCTION

Foundational mathematics courses, particularly algebra and calculus, play a decisive role in the academic trajectory of students enrolled in STEM programs. Numerous studies have demonstrated that performance in these initial courses is a significant predictor of persistence and academic success in scientific and engineering careers [1]. In many university contexts, mathematics functions as a gatekeeper course, determining not only immediate performance but also continuity within STEM pathways. Indeed, interventions such as remedial courses have been shown to significantly improve subsequent performance in mathematics, thereby strengthening academic resilience and student retention [2].

Beyond conceptual mastery, psychosocial factors such as self-efficacy, mathematics anxiety, and interest in the discipline directly influence students' persistence in STEM [3]. Programs that strengthen students' sense of belonging and academic identity tend to improve retention rates, highlighting that performance is not solely a cognitive matter but also motivational and contextual. In this regard, innovative instructional designs that integrate real-world applications and computational thinking have demonstrated increased engagement and persistence in foundational mathematics courses [4]. Similarly, pedagogical strategies that provide immediate feedback and multiple opportunities for attempts enhance self-efficacy and persistence in mathematics [5].

In recent years, artificial intelligence–driven adaptive learning systems have emerged as promising tools for strengthening behavioral engagement and academic performance. Several studies indicate that the use of adaptive platforms is positively associated with improved academic outcomes and higher levels of engagement [6], [7], [8]. In engineering and computer science contexts, AI-based learning tools have been shown to significantly enhance conceptual understanding and academic performance [9]. Specifically, a meta-analysis of the ALEKS system found that its complementary use alongside traditional instruction produces significant positive effects on mathematics achievement (Hedges' $g = 0.43$), demonstrating effectiveness comparable to conventional instruction [10].

However, the specific mechanism through which these platforms influence academic performance remains under examination. Traditionally, time on task has been considered a relevant predictor of academic achievement. Studies have reported positive correlations between study time and university grades [11], although this relationship may vary substantially depending on the course and context [12]. Furthermore, evidence suggests that exposure time alone does not always produce significant improvements in performance [13], raising questions about the distinction between passive exposure and active engagement.

From a cognitive perspective, the theory of deliberate practice posits that performance improvement occurs through structured activities involving sustained cognitive effort, active problem solving, and continuous feedback [14]. Traditional mathematics education based exclusively on repetitive exercises may lead to the automation of basic skills but does not necessarily foster flexible and adaptive knowledge. In contrast, multiple studies demonstrate that practice volume is strongly associated with performance gains and skill acquisition [15], reducing error rates and attentional demands as experience increases [16].

In digital environments, indicators of active engagement—such as the number of correct responses, completed tasks, or viewed resources—have been identified as stable predictors of academic success [17]. Likewise, early performance in initial assignments and midterm assessments constitutes a strong indicator of final course outcomes [18]. In this context, learning analytics has demonstrated the capacity to diagnose performance problems early by analyzing interaction logs in STEM courses, achieving high predictive accuracy [19]. In more advanced predictive models, techniques such as multiple linear regression combined with principal component analysis have improved predictive precision by addressing limitations of traditional statistical modeling approaches [20].

Despite this growing body of evidence, a relevant gap persists in the literature: the need to empirically distinguish between the effect of exposure time and adaptive practice volume as predictors of academic performance in foundational STEM courses. Although time on task has been widely studied, there is less clarity regarding whether the number of completed exercises particularly in adaptive environments such as ALEKS constitutes a more robust predictor of performance and academic risk.

The present study analyzes the differential impact of time on platform and the number of adaptive exercises completed on academic performance in an Algebra I course within STEM programs, integrating linear and logistic regression models to examine both explained variance in performance and the probability of low academic achievement.

MATERIALS AND METHODS

Study Design

A quantitative, observational, cross-sectional study was conducted based on the secondary analysis of academic data generated by an adaptive learning platform. The study is framed within a learning analytics approach aimed at examining usage and performance patterns in digital environments within STEM courses.

Participants and Context

The sample consisted of students enrolled in an Algebra I course within STEM academic programs during the first academic term of 2025. Students were drawn from multiple engineering programs, allowing the analysis of learning behavior in a common foundational course across STEM educational pathways.

The total sample size was N = 567 students.

Data Source and Procedure

Data were extracted directly from the ALEKS platform at the end of the academic term. The dataset included only statistical indicators of performance and system usage, without incorporating personally identifiable information.

All variables correspond to automatically generated platform metrics, ensuring objectivity in data recording and eliminating self-report bias.

Variables

The study included two primary independent variables derived from the ALEKS adaptive system.

The first was Time On Platform, measured in cumulative hours per student during the analyzed academic term. This variable represents the level of exposure to the digital learning environment.

The second independent variable was Adaptive Exercises, defined as the total number of adaptive exercises completed by each student within the system. Since ALEKS dynamically adjusts exercise difficulty and sequencing according to individual performance, this variable reflects the volume of personalized practice undertaken by each participant.

Additionally, a derived indicator termed Adaptive Intensity was constructed, calculated as the ratio of completed exercises to hours spent on the platform. This index represents academic productivity per unit of time, allowing differentiation between passive exposure and effective engagement within the adaptive system.

The dependent variable was the Final Score, expressed as a percentage-based grade generated by the platform. This indicator reflects the level of mastery achieved in the Algebra course within STEM programs.

To model academic risk patterns, a binary variable named Performance Level was created. This variable was recoded using a 70% academic cutoff, where 0 indicated adequate performance and 1 indicated low performance. This variable was used in logistic regression analyses.

Academic Efficiency Indicator

To complement the predictive analysis, a second derived indicator, Academic Efficiency, was constructed. It was defined as the ratio between final grade and hours spent on the platform. This index evaluates performance achieved per unit of time, providing an optimization perspective on learning within adaptive STEM environments.

All continuous variables were treated as such in correlational and linear regression analyses. The binary performance variable was used exclusively in logistic regression models to estimate the probability of low academic performance.

Statistical Analysis

Statistical analyses were conducted using jamovi (version 2.7.12.0). First, descriptive statistics were calculated for all continuous variables (mean, standard deviation, minimum, maximum), and distributions were inspected using skewness and kurtosis, as well as visualizations (histograms and scatterplots) to identify patterns and potential outliers.

Subsequently, bivariate Pearson correlations were estimated among Time On Platform, Adaptive Exercises, Adaptive Intensity, Academic Efficiency, and Final Score.

For predictive purposes, a multiple linear regression model was fitted using Final Score as the dependent variable and Time On Platform and Adaptive Exercises as predictors. Unstandardized coefficients (B), standard errors, t-values, significance levels, and model fit indices (R^2 and adjusted R^2) were reported. Multicollinearity was examined using variance inflation factors (VIF) and tolerance values.

Finally, to analyze academic risk, a binary logistic regression model was estimated using Performance Level (0 = adequate; 1 = low performance) as the dependent variable, including Time On Platform and Adaptive Exercises as predictors (and derived indicators when appropriate). Odds ratios (OR), 95% confidence intervals, and model significance tests were reported.

Ethical Considerations

The study exclusively used anonymized statistical data generated by the institutional platform, without access to personally identifiable information. As this constituted a secondary analysis of aggregated and de-identified academic records, individual informed consent was not required..

RESULTS

Descriptive Statistics

The sample consisted of N = 567 STEM students enrolled in Algebra I during the first academic term of 2025, with no missing values in the analyzed variables.

The average time spent on the platform was M = 18.0 hours (SD = 15.7), with a median of 14 hours and a range from 0.4 to 111 hours. The distribution exhibited positive skewness (skewness = 1.83) and elevated kurtosis (4.99), indicating a concentration of cases at lower values with the presence of students who accumulated substantially higher amounts of time.

Regarding adaptive practice, students completed an average of 183 exercises (SD = 66.6), with a median of 190 and a range from 41 to 370 exercises. Skewness was moderate (skewness = 0.75), suggesting a relatively more balanced distribution compared to time on platform.

The average final score was 72.6 (SD = 20.9), with a median of 78 and values ranging from 31 to 100. The distribution showed slight negative skewness (skewness = −0.41), indicating a concentration of scores in the mid-to-high performance range.

Regarding derived indicators, adaptive intensity showed a mean of 27.2 exercises per hour (SD = 47.5), with pronounced positive skewness (skewness = 5.46) and extremely high kurtosis (41.0), indicating the presence of extreme outliers associated with combinations of low time and high exercise volume.

Similarly, the academic efficiency index showed a mean of 10.4 points per hour (SD = 18.3), with marked positive skewness (skewness = 6.05) and elevated kurtosis (49.8), suggesting a highly concentrated distribution with the presence of extreme cases.

TABLE 1
DESCRIPTIVE STATISTICS OF LEARNING ANALYTICS INDICATORS IN STEM ALGEBRA I (N = 567)

	TP	AE	FS	AI	AEf
Mean	18.0	183	72.6	27.2	10.4
Median	14.0	190	78.0	12.8	5.28
Standard deviation	15.7	66.6	20.9	47.5	18.3
Skewness	1.83	0.751	-0.407	5.46	6.05
Std. error skewness	0.103	0.103	0.103	0.103	0.103
Kurtosis	4.99	0.853	-1.07	41.0	49.8
Std. error kurtosis	0.205	0.205	0.205	0.205	0.205

Note. TP (Time_On_Platform) is expressed in accumulated hours within the ALEKS system. AE (Adaptive_Exercises) represents the total number of adaptive exercises completed. FS (Final_Score) corresponds to the percentage-based final grade provided by the platform. AI (Adaptive_Intensity) was computed as AE divided by TP. AEf (Academic_Efficiency) was computed as FS divided by TP. Skewness and kurtosis values are reported to assess distributional properties of each variable.

Correlations Between Usage Indicators and Academic Performance

Pearson correlations were estimated between platform usage indicators and academic performance (Table 2).

Time_On_Platform (TP) showed a positive but weak correlation with Final_Score (FS), r = .128, p = .002, suggesting that longer time spent in the system is associated with modest increases in academic performance.

In contrast, the number of completed Adaptive_Exercises (AE) demonstrated a strong and positive correlation with Final_Score, r = .692, p < .001, indicating that the volume of adaptive practice constitutes a substantial predictor of academic achievement.

Time_On_Platform was not significantly associated with the number of exercises completed (r = −.039, p = .348), suggesting that mere connection time does not necessarily imply greater effective practice within the system.

Derived indicators revealed relevant patterns. Adaptive_Intensity (AI) was negatively correlated with Time_On_Platform (r = −.415, p < .001), indicating that higher accumulated hours tend to be associated with lower relative productivity per unit of time. However, AI did not show a significant association with Final_Score ($r = .065$, $p = .123$).

Academic_Efficiency (AEf) showed a moderate negative correlation with Time_On_Platform ($r = -.404$, $p < .001$) and an almost perfect association with Adaptive_Intensity ($r = .977$, $p < .001$), evidencing structural overlap between both derived indicators.

TABLE 2
PEARSON CORRELATION MATRIX AMONG LEARNING ANALYTICS INDICATORS (N = 567)

Variable	1	2	3	4	5
1. TP	—				
2. AE	−.039	—			
3. FS	.128**	.692***	—		
4. AI	−.415***	.194***	.065	—	
5. AEf	−.404***	.109*	.081	.977***	—

Note. TP = Time_On_Platform (accumulated hours in ALEKS); AE = Adaptive_Exercises (total adaptive exercises completed); FS = Final_Score (percentage-based final grade); AI = Adaptive_Intensity (AE / TP); AEf = Academic_Efficiency (FS / TP). Pearson two-tailed correlations are reported. p < .05; p < .01; p < .001.

Multiple Linear Regression Analysis

A multiple linear regression analysis was conducted to evaluate the effect of Time_On_Platform (TP) and the number of completed Adaptive_Exercises (AE) on Final_Score (FS) in the Algebra I course within STEM programs.

The model was statistically significant and explained 50.2% of the variance in academic performance ($R^2 = .502$), indicating substantial predictive capacity of platform usage indicators on final performance (see Table 3).

Regarding individual predictors, the number of completed adaptive exercises emerged as the strongest predictor of performance ($\beta = .698$, $p < .001$), as shown in Table 3. This result suggests that the volume of adaptive practice constitutes the primary determinant of academic achievement within the digital environment. The positive relationship between the number of exercises completed and the final grade can be clearly observed in Figure 1, which displays a consistent upward trend between both variables.

Time_On_Platform also showed a positive and statistically significant effect ($\beta = .155$, $p < .001$), although of considerably smaller magnitude (see Table 3). This indicates that, while time spent in the system contributes to performance, its impact is substantially lower than that associated with effective practice.

TABLE 3
MULTIPLE LINEAR REGRESSION PREDICTING FINAL SCORE FROM PLATFORM USAGE INDICATORS (N = 567)

Predictor	B	SE	β	t	p
Intercept	28.896	1.973	—	14.64	< .001
TP	0.207	0.0396	.155	5.22	< .001
AE	0.218	0.0093	.698	23.48	< .001
Model fit: R = .709, R² = .502, Adjusted R² ≈ .500					

Note. TP = Time_On_Platform; AE = Adaptive_Exercises. Unstandardized (B) and standardized (β) coefficients are reported. Dependent variable: FS (Final_Score).

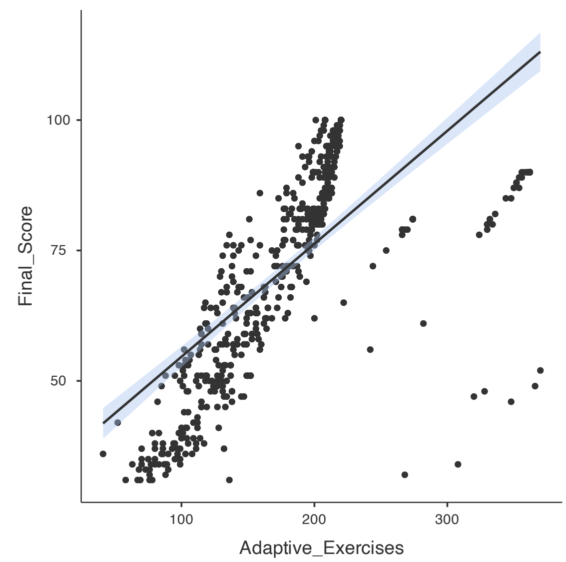

Figure 1
Relationship Between Adaptive Practice and Final Academic Performance in STEM Algebra I

Note. Each point represents an individual STEM student (N = 567). The fitted line represents the linear regression trend between adaptive exercises completed and final academic performance.

Binary Logistic Regression

A binary logistic regression analysis was conducted to evaluate the effect of Time_On_Platform and the number of completed Adaptive_Exercises on the probability of low academic performance.

The model demonstrated adequate fit (McFadden's $R^2 = .517$), indicating substantial explanatory capacity in predicting academic risk.

The number of completed adaptive exercises emerged as a significant predictor of low performance ($B = -0.051$, $p < .001$). The odds ratio (OR = 0.950; 95% CI [0.943, 0.958]) indicates that each additional exercise reduces the probability of low academic performance by approximately 5%.

In contrast, Time_On_Platform did not show a statistically significant effect when controlling for the volume of adaptive practice ($B = -0.017$, $p = .060$), suggesting that time spent in the system alone does not constitute a determining factor of academic risk.

The model demonstrated high classification accuracy, correctly identifying 94.7% of cases with adequate performance and 88.7% of cases with low performance.

TABLE 4
BINOMIAL LOGISTIC REGRESSION PREDICTING LOW ACADEMIC PERFORMANCE

Predictor	B	SE	OR	95% CI	p
TP	−0.0168	0.0089	0.983	[0.966, 1.001]	.060
AE	−0.0511	0.0040	0.950	[0.943, 0.958]	< .001

Model fit: R^2 McFadden = .517
N = 567

DISCUSSION

The present study examined the role of time on platform and adaptive practice in predicting academic performance in an Algebra I course within STEM programs. The results consistently showed that the volume of completed adaptive exercises constitutes the primary predictor of academic performance, substantially exceeding the effect of accumulated connection time.

From a quantitative standpoint, adaptive practice demonstrated a strong correlation with final grade ($r = .692$) and emerged as the dominant predictor in the linear regression model ($\beta = .698$), explaining together with time more than 50% of the variance in academic performance ($R^2 = .502$). Likewise, in the logistic model, each additional exercise reduced the probability of low academic performance by approximately 5% ($OR = 0.950$), confirming its protective effect. These findings are consistent with the literature on deliberate practice, which posits that performance improvement depends on structured activities involving sustained cognitive effort and continuous feedback [1]. Previous research has likewise demonstrated that practice volume is strongly associated with skill acquisition and retention, reducing errors and attentional demands as experience increases [2], [3].

In contrast, time on platform showed a positive but considerably smaller effect and became non-significant when controlling for the number of exercises in the logistic model. This finding nuance prior evidence reporting positive associations between time on task and academic performance [4], suggesting that this relationship may vary depending on course context [5]. Moreover, research in other domains has shown that prolonged exposure alone does not necessarily lead to significant performance gains [6]. Consequently, the present findings reinforce the distinction between passive exposure and active engagement, indicating that learning in STEM contexts depends more on effective cognitive work than on accumulated time.

From a pedagogical perspective, these results imply that instructors should seek an appropriate balance in exercise assignment, particularly in content areas historically associated with greater conceptual difficulty. The literature on foundational STEM courses has highlighted that early mathematics performance is a determinant of academic persistence [7], suggesting that optimizing adaptive practice may have indirect effects on retention. In this regard, adaptive learning systems that provide immediate feedback and multiple attempts have been shown to strengthen self-efficacy and persistence in mathematics [8], as well as to increase behavioral engagement and academic performance [9], [10].

The findings also underscore the importance of raising students' awareness regarding the value of the number of assigned exercises. Indicators of active engagement—such as completed tasks and correct responses—have been identified as stable predictors of academic success [11], supporting the idea that practice volume is not arbitrary but rather a central component of effective learning. In adaptive platforms such as ALEKS, whose effectiveness as a complement to traditional instruction has been supported by meta-analytic evidence [12], sustained engagement with assigned activities translates into tangible performance improvements.

A particularly relevant finding is that time assumes differential meaning depending on the student profile. Those with larger prior gaps in mathematical competencies require greater time investment and higher exercise volume to achieve satisfactory results, consistent with research highlighting the importance of early remedial interventions to improve academic resilience [13]. As students consolidate conceptual mastery, the time required to solve exercises decreases, reflecting processes of automation and cognitive efficiency.

From an institutional perspective, the evidence supports the development of early alert strategies based on learning analytics. Previous studies have shown that interaction logs in STEM platforms can be used to predict performance with high accuracy [14] and that advanced regression models can enhance predictive capacity [15]. In this context, early identification of students with low adaptive practice may contribute to retention strategies in mathematics courses that historically function as gatekeepers within STEM programs.

Finally, the protective effect observed in the logistic regression provides empirical validation for the use of adaptive systems such as ALEKS as a structural complement in mathematics education within STEM careers. In line with studies demonstrating significant improvements in engagement and comprehension through AI-driven tools [16], the present results position adaptive practice not as a supplementary resource but as a strategic component in the curricular design of foundational courses.

From an academic governance perspective, the findings suggest that adaptive practice indicators can be integrated into institutional early monitoring systems. Incorporating behavioral metrics derived from digital platforms allows institutions to shift from reactive intervention models to predictive, data-informed frameworks, optimizing retention strategies in STEM programs where mathematics courses act as critical filters.

In terms of engineering curriculum design, the findings support the structured incorporation of adaptive practice as a mandatory component in foundational courses. Rather than emphasizing hours of exposure, instructional design should focus on progressive exercise sequences that ensure conceptual mastery before advancing to subsequent content, aligning with mastery learning and performance-based approaches.

Although the study focused on Algebra I, the observed patterns may be generalizable to other foundational STEM courses characterized by high procedural load and conceptual sequentially such as calculus, introductory physics, or basic programming where active engagement with structured tasks is essential for effective learning.

Despite the strong explanatory capacity of the analyzed indicators, several methodological limitations should be acknowledged. First, the cross-sectional design precludes definitive causal inferences between adaptive practice and academic performance. Second, the data derive from a single Algebra I course within a specific institutional context, which may limit direct generalizability to other educational environments. Additionally, psychosocial variables and prior academic background were not included, although these factors could influence performance and enrich future predictive models. Finally, although the model demonstrated high explanatory capacity, cross-validation techniques were not applied; future research could strengthen predictive robustness through longitudinal or comparative designs.

Overall, the findings reinforce the importance of integrating learning analytics into pedagogical decision-making, demonstrating that digital platform usage data can provide valuable insights for optimizing learning and strengthening retention in STEM programs.

CONCLUSIONS

The present study provides clear empirical evidence regarding the differential role of platform usage indicators in adaptive learning environments within foundational mathematics courses in STEM programs. The findings indicate that adaptive practice constitutes a central mechanism for academic achievement, emerging as a more consistent predictor of performance than accumulated time spent on the platform.

These results contribute to the field of engineering education by distinguishing between exposure and effective engagement, offering quantitative evidence that supports the strategic incorporation of adaptive systems as structural complements in Algebra I courses. The evidence suggests that monitoring the volume of completed exercises may function as an early indicator of academic performance and risk, strengthening data-informed pedagogical decision-making.

From a curricular perspective, the findings encourage a reconsideration of activity design in introductory STEM courses, emphasizing the importance of progressive and personalized practice sequences. Furthermore, the integration of learning analytics into academic management may enhance retention strategies, particularly in subjects that historically present higher failure rates.

Finally, the study opens new avenues for research aimed at exploring more advanced predictive models, incorporating psychosocial variables, and conducting longitudinal evaluations of the impact of adaptive practice on STEM academic trajectories.

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