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Do Diagnostic Measures in Calculus Work?

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Abstract

At universities around the world, quality assurance standards define learning outcomes for Calculus I and II. An often-debated question is how to predict learning outcomes in STEM courses with high withdrawal rates and poor performance. The present study was intended to determine whether faculty-developed diagnostic tests, which assessed the readiness of students' knowledge and skills, and engagement measures could predict learning outcomes in Calculus I and II. Attendance in the first six weeks of the semester served as a measure of behavioral engagement, whereas self-efficacy served as a measure of dispositional engagement. In this study, the diagnostic test of Calculus I predicted skill-related learning outcomes, whereas most measures predicted skill-related learning outcomes in Calculus II. Within an action research protocol, our findings suggest that readiness is to be enhanced to improve students' chances of academic success as defined by quality assurance standards.

Keywords: *Diagnostic test; Calculus; engagement.*

1. Introduction

Before, during, and after enrolling in Calculus, students frequently joke that the road to the completion of the Calculus sequence is a bumpy one. Their joke is an explicit recognition that the acquisition of knowledge and skills in Calculus may be difficult. The present study is motivated by the need to determine whether students' attainment of the learning outcomes set by quality assurance standards for Calculus can be predicted early in the semester. The goal is to identify at-risk students at the time remedial actions can be most effective.

Across courses and disciplines, a great deal of research has been done on the predictive validity of a variety of tools to understand the sources of students' academic success (e.g., Ismail & Yusof, 2023). Yet, individual differences in student populations exist, which require local answers to broad questions if tools are to be useful to the particular population of interest. Thus, in our study, we focus on a unique population of female students who only recently have been granted rights similar to those of men. In a society emerging from patriarchy, female students pursuing STEM (i.e., Science, Technology, Engineering, and Mathematics) degrees are challenged to not only learn science-related matters but also dispel archaic gender stereotypes (Alghamdi & Almazroa, 2024). These stereotypes discourage them from pursuing STEM fields by questioning their abilities and suitability (Alghneimin et al., 2024). Given the recency of gender-equity legal standards, archaic gender stereotypes may be particularly robust among the women of our study, thereby having the potential of jeopardizing their academic success.

Students' successful learning and performance in academic courses, including Calculus, is generally conceived as arising from two key factors: students' pre-requisite competencies, as defined by knowledge and skills, and engagement. Concerning pre-requisite Calculus competencies, the extant literature has highlighted weaknesses in students' foundational knowledge, which is necessary to work with functions, and their ability to perform algebraic manipulations (Lawson, 2003). Thus, the fundamental goal of assessment at the start of a Calculus course is to identify, through the administration of a diagnostic test, areas of weakness that can impede students' learning of Calculus materials. Yet, students' likelihood of success in Calculus also depends on their engagement (Waheed et al., 2024). According to self-determination Theory (SDT), students' academic engagement is fostered by self-efficacy (Goldman et al., 2016). The latter is a disposition that reflects students' confidence in their abilities to get things done and overcome obstacles by finding remedies. Thus, students with high self-efficacy may see Calculus as a challenge to be mastered. Instead, students with low self-efficacy may view Calculus as a threat, thereby increasing their chances of withdrawing from the course and switching academic majors. A correlate of self-efficacy is behavioral engagement, which exemplifies the amount of time and effort devoted to course activities (Hofverberg et al., 2022). Not surprisingly, it has been reported as capable of influencing students' attainment of learning outcomes (Doo & Kim, 2024; Hyofverberg et al., 2022).

Of course, in many fields, including Calculus, controversy exists regarding the relative contribution of cognitive factors (i.e., pre-existing competencies involving knowledge and skills) and motivational factors (e.g., engagement) to learning outcomes (Abín et al., 2020; Fonteyne et al., 2017). One of the reasons is that a variety of diagnostic assessment measures exist, including standardized and locally developed tests. Tools used to measure academic motivation, which defines students' engagement in a course, may also vary from population to population. Thus, assessment tools need to be selected or developed to suit the student population that educators at a given university serve (Pilotti et al., 2022). With such tools, the present study asks whether diagnostic measures of knowledge and skills before the start of either Calculus I or Calculus II predict the learning outcomes of each course above and beyond measures of engagement.

The STEM female students selected for the study are pursuing an undergraduate degree in either Engineering or Computer Science taught in a foreign language (English), thereby adding language to the challenges arising from gender stereotypes. Detracting from such challenges is the mode of instruction, which is student-centered, encouraging teamwork and peer support. Yet, the selected students perceive Calculus II as much more difficult than Calculus I, questioning whether perceived difficulty may shape the predictive validity of readiness and engagement measures. For this unique population, the following questions are asked, each followed by a hypothesis to be tested:

Q1 Do Calculus I and II differ in readiness, engagement, and attainment? If the subjective difficulty of the materials taught in Calculus I and II is relevant, readiness and attainment should be higher for Calculus I, whereas behavioral engagement may display the opposite pattern (H1a). That is, the more a course is perceived as challenging, the more students will devote time and effort to it. No differences should be recorded in engagement as a disposition because students in either course come from the same pool (H1b).

Q2 What is the contribution of knowledge and skill readiness (as measured by a diagnostic test) as well as engagement to learning outcomes in Calculus I and II? It is reasonable to hypothesize that the perceived difficulty of the courses may render the readiness and engagement measures more sensitive to performance. Thus, the contribution of readiness and engagement to learning outcomes may vary between Calculus I and II (H2).

2. Method

2.1. Participants

The participants were 315 female undergraduate students who were enrolled in either Calculus I (n = 128) or Calculus II (n = 187). They were pursuing a STEM degree in either Engineering or Computer Science. Their age ranged from 18 to 25. Students' first language was Arabic. English, which was used for Calculus instruction, was their second language. Prior to university enrollment, students' English proficiency had been judged equivalent to that of modest or competent users (as per IELTS).

2.2. Materials and Procedure

At the start of the Fall semester, students enrolled in either Calculus I or Calculus II were given a 10-problem diagnostic test related to the foundational knowledge and skills that participants were expected to possess. Students had 20 minutes to solve the problems of the diagnostic test. Three PhD-level instructors who had been teaching these courses for more than a decade selected the problems from the diagnostic sections of the textbooks that students would be using for either course (e.g., Stewart, 2016). For Calculus I, problems entailed the following Algebraic concepts: (a) equations and inequalities, (b) graphs of linear equations and inequalities, (c) exponents and polynomials, (d) factoring, (e) rational expressions, and (f) roots and radicals. For Calculus II, problems covered the following concepts: (a) functions and models, (b) differentiation rules, and (c) integrals. The reliability of each diagnostic test, as measured by Cronbach's Alpha, was 0.72 for Calculus I and 0.82 for Calculus II. The face validity of each diagnostic test was assessed in pilot work through 9 students who had completed both courses.

In addition to the diagnostic measure, students completed the self-efficacy questionnaire of Chen et al. (2001). The questionnaire contained 8 statements about confidence in one's abilities. Before considering each statement, students were asked to focus on their performance in Mathematics courses so that their confidence reports would specifically concern Mathematics. Then, students indicated the degree of agreement with each statement on a 5-point scale from strongly disagree (0) to strongly agree (4). Self-efficacy values were used as indices of students' disposition to be engaged. Attendance records in the first 6 weeks of the semester were also collected to serve as indices of behavioral engagement (i.e., the amount of time and effort devoted to course activities; Pilotti & El Alaoui, 2023).

Students' performance was assessed through 3 tests (45%), quizzes (15%), in-class and homework activities (10%), and the final test (30%). At the end of the semester, students' performance was organized into three learning outcomes per course: knowledge (K), Skill (S; i.e., application of knowledge and interpretation of outcomes), and Teamwork (T; i.e., demonstration of collaborative skills for problem-solving applied to in-class and homework activities). In the student-centered instructional context of Calculus classes, collaboration among students in class activities was fostered by instructors to diminish the anxiety that frequently accompanies learning. Thus, the T dimension was included as one of the learning outcomes to measure the extent to which collaboration was pursued by students. For all variables, raw scores were translated into percentages to ensure uniformity in the values submitted to statistical analyses.

2.3. Assessment of Course Difficulty

An additional group of 15 students who had completed Calculus I and II in earlier semesters was asked to rate the difficulty of each course. A 5-point scale from very easy (0) to very difficult (4) was used for evaluation. On this scale, the neutral value was 2. Students' ratings of Calculus II ranged between 3 and 4 [$M = 4.14$; $SEM = 0.11$]. Instead, for Calculus I, ratings were more variable, ranging from 1 to 3 [$M = 2.27$; $SEM = 0.15$]. In sum, Calculus II was judged as more difficult than Calculus I [$t(14) = 11.50$, $p < 0.001$].

3. Results

Only 101 Calculus I students and 165 Calculus II students completed the course (79% and 88%, respectively). Thus, the analyses described below involve 266 students. The descriptive statistics (mean, *M*, and standard error of the mean, *SEM*) are presented in Table 1. Overall, students' readiness was poor. Except for teamwork, equally poor was the attainment of learning outcomes measuring knowledge and skills at the end of both courses. In contrast, at the start of the course, students' engagement, measured as either a disposition or a behavior, was adequate.

Table 1. Descriptive statistics of key variables (scale range: 0-100)

Variables	**Indices**	*Calculus I*		*Calculus II*	
		M	*SEM*	*M*	*SEM*
Diagnostic Test	Readiness	62.34	2.18	57.67	1.98
Self-Efficacy	Engagement (Disp.)	80.05	1.23	77.04	1.13
Attendance	Engagement (Behav.)	87.28	0.85	87.41	0.68
LO: Knowledge		66.54	1.75	74.37	1.42
LO: Skills		69.49	1.90	71.63	1.28
LO: Teamwork		98.19	0.71	97.71	0.47

Below, the results of inferential statistics are displayed. Statistics are considered significant at the 0.05 level. To understand whether Calculus I and II differed in readiness, engagement, and attainment, one-way ANOVAs were computed. Students' readiness and engagement did not differ [Fs ≤ 2.09, *ns*]. However, at the end of the semester, Calculus II students exhibited higher attainment of knowledge than Calculus I students [$F(1, 264) = 11.85$, $MSE = 324.01$, $p = 0.001$, *Partial Eta*^{2} $= 0.04$]. The other learning outcomes were not significantly different between Calculus I and II [Fs <1, *ns*]. H1a or H1b were not supported.

Did indices of readiness and engagement predict course learning outcomes? Table 2 displays the Pearson correlation coefficients (r) illustrating the binary relationships between predictors and learning outcomes (LO). The selected predictors accounted more broadly for learning outcomes in Calculus II than in Calculus I.

Table 2. Correlation coefficients

Variables	**Indices**	LO Knowledge	LO Skills	LO Teamwork
Calculus I				
Diagnostic Test	Readiness	*ns*	+.23	*ns*
Self-Efficacy	Engagement (Disp.)	*ns*	*ns*	*ns*
Attendance	Engagement (Behav.)	*ns*	*ns*	*ns*
Calculus II				
Diagnostic Test	Readiness	*ns*	+0.35	+0.34
Self-Efficacy	Engagement (Disp.)	+0.18	+0.20	+0.17
Attendance	Engagement (Behav.)	*ns*	+0.30	+0.29

Table 3 displays the results of linear regression analyses with skill learning as the outcome variable, which was considered the most relevant learning outcome by the faculty teaching Calculus. In contrast to correlations, regression analyses assessed the relative contribution of predictors (i.e., readiness and engagement as either a disposition or a behavior) to learning outcomes. Multicollinearity was ruled out (average VIF ≤ 1.11 and tolerance ≥ 0.86). We found that readiness, as measured by the diagnostic test, predicted the skills acquired in both Calculus I and II. However, attendance (indexing students' engagement as behavior) also predicted the skills acquired in Calculus II. When skill learning was treated as the only outcome variable, H2 was partially supported as the contribution of self-efficacy (an index of dispositional engagement) was null.

Table 3. Regression analyses with skills as the learning outcome

Predictors	**Indices**	*Beta*		*t*	Sign. (*p*)
Calculus I	(R =0.28)				
Diagnostic Test	Readiness	0.217	.082	2.06	0.035
Self-Efficacy	Engagement (Disp.)	0.154	.129	1.58	*ns*
Attendance	Engagement (Behav.)	0.009	.204	0.09	*ns*
Calculus II	(R =0.45)				
Diagnostic Test	Readiness	.301	.043	4.21	< 0.001
Self-Efficacy	Engagement (Disp.)	.127	.076	1.77	*ns*
Attendance	Engagement (Behav.)	.239	.130	3.32	0.001

4. Discussion

The results of the present study can be summarized in three points. First, although Calculus II was judged by students to be more difficult than Calculus I, readiness was poor in both. Evidence that students are struggling in Mathematics courses is not novel (Bakr Khoshaim & Ali, 2015). In our study, however, there were also no differences in engagement early in the semester. Second, when predictors were considered separately (as per correlation analyses), they were more effective in estimating learning outcomes in Calculus II than in Calculus I. Their effectiveness was selective though. Namely, they mostly predicted learning outcomes concerning skills and students' ability to work together. In debriefing sessions, students unanimously described Calculus II as a very difficult course. As such, they often reported relying on each other and the instructor for advice and guidance. They voiced an appreciation for collaborative activities viewed as fostering learning and decreasing anxieties. In Calculus I, such reports were rare. Thus, the relative perceived difficulty of the two courses may have made Calculus II more sensitive to the value of teamwork. Third, when predictors were examined together, readiness (as measured by the diagnostic test) was found to forecast students' attainment of skill-related competencies in both courses. However, in Calculus II, behavioral engagement (as measured by early attendance records) also predicted students' attainment of skill-related competencies. Thus, when a course is perceived as difficult, behavioral engagement can make a difference in students' ability to succeed.

Our study took a local approach to the prediction of Calculus learning outcomes. The goal was to not only increase educators' understanding of this unique sample of women pursuing STEM degrees but also develop suitable interventions. After completing the first step of this action research (Sáez Bondía & Cortés Gracia, 2022), which intended to understand students, the next step was to implement remedies for readiness rather than engagement.

Currently awaiting administrative approval, several remedies were proposed to enhance the attainment of the learning outcomes set by quality assessment protocols. For instance, to address students' poor readiness, proposals entailed offering more opportunities for practicing skills and reiterating knowledge across all Math courses (including Calculus prerequisites). Another proposed intervention consisted of making the assessment of performance in earlier courses more uniform and stringent. The re-design of Mathematics materials and tutoring services was also considered to foster learning across the entire duration of a Calculus course.

Our study has limitations that may be addressed in future studies. The cross-sectional design of our study does not provide information about how individual students change from Calculus I to Calculus II. Thus, our study does not have the advantages of a longitudinal design. However, it compares groups taught by the same instructors, thereby preserving consistency in instructional idiosyncrasies. The characteristics of the sample of young women who participated in the study may limit the generalizability of its results. Calculus is taught in students' second language, which adds a layer of challenges that other students may not experience. Furthermore, participants are from a society undergoing societal and economic changes that are transforming a patriarchal order into a system affirming gender equity. These women have only recently been granted educational and professional opportunities similar to those of men (Mozahem, 2021). Thus, our findings may not apply to male students from the same society who are now competing with women for educational and professional opportunities (Barry, 2019). Evidence exists that past privileges may have fostered males' underachievement.

References

Abín, A., Núñez, J. C., Rodríguez, C., Cueli, M., García, T., & Rosário, P. (2020). Predicting mathematics achievement in secondary education: The role of cognitive, motivational, and emotional variables. *Frontiers in Psychology, 11*, 876. https://doi.org/10.3389/fpsyg.2020.00876

Alghamdi, A. K., & Almazroa, H. (2024). Saudi women STEM pioneers: Penetrating the mud ceiling. *Frontiers in Psychology*, *15*, 1347944. https://doi.org/10.3389/fpsyg.2024.1347944

Alghneimin, J., Varga, A., & Kovacs, M. (2024). Gender disparities and potentials in STEM approach in Jordan and Saudi Arabia–An analytical literature review. *Hungarian Educational Research Journal, 14*(2), 217-230. https://doi.org/10.1556/063.2023.00236

Bakr Khoshaim, H., & Ali, T. (2015). Students' struggle with first-year university mathematics courses in Saudi Arabia. *College Student Journal*, *49*(4), 588-598. https://eric.ed.gov/?id=EJ1095432

Barry, A. (2019). Gender differences in academic achievement in Saudi Arabia: A wake-up call to educational leaders. *International Journal of Education Policy and Leadership*, *15*(15), 1-17. https://eric.ed.gov/?id=EJ1240561

Chen, G., Gully, S. M., & Eden, D. (2001). Validation of a new general self-efficacy scale. *Organizational Research Methods, 4*(1), 62-83. https://doi.org/10.1177/109442810141004

Doo, M. Y., & Kim, J. (2024). The relationship between learning engagement and learning outcomes in online learning in higher education: A meta-analysis study. *Distance Education*, *45*(1), 60-82. https://doi.org/10.1080/01587919.2024.2303484

Fonteyne, L., Duyck, W., & De Fruyt, F. (2017). Program-specific prediction of academic achievement on the basis of cognitive and non-cognitive factors. *Learning and Individual Differences*, *56*, 34-48. https://doi.org/10.1016/j.lindif.2017.05.003

Goldman, Z. W., Goodboy, A. K., & Weber, K. (2016). College students' psychological needs and intrinsic motivation to learn: An examination of self-determination theory. *Communication Quarterly, 65*(2), 167-191. https://doi.org/10.1080/01463373.2016.1215338

Hofverberg, A., Winberg, M., Palmberg, B., Andersson, C., & Palm, T. (2022). Relationships between basic psychological need satisfaction, regulations, and behavioral engagement in mathematics. *Frontiers in Psychology*, *13*, 829958. https://doi.org/10.3389/fpsyg.2022.829958

Ismail, N., & Yusof, U. K. (2023). A systematic literature review: Recent techniques of predicting STEM stream students. *Computers and Education: Artificial Intelligence*, *5*, 100141. https://doi.org/10.1016/j.caeai.2023.100141

Lawson, D.A. (2003). Changes in student entry competencies 1991-2001. *Teaching Mathematics and Its Applications, 22*(4), 171-175. https://doi.org/10.1093/teamat/22.4.171

Mozahem, N. A. (2021). Gender, education, and career in the Arab world: A literature review. *Research in Education, 111*(1), 141-163. https://doi.org/10.1177/00345237211034883

Pilotti, M. A., Abdelsalam, H. M., Anjum, F., Daqqa, I., Muhi, I., Latif, R. M., Nasir, S., & Al-Ameen, T. A. (2022). Predicting math performance of Middle Eastern students: The role of dispositions. *Education Sciences, 12*(5), 314. https://doi.org/10.3390/educsci12050314

Pilotti, M., & El Alaoui, K. (2023). Lessons Learned from Online and Face-to-Face Courses: To What Extent Is Students' Academic Success Just a Matter of Showing Up? T*he International Journal of Assessment and Evaluation, 30*(1), 15-32. https://doi.org/18848/2327-7920/CGP/v30i01/15-32

Sáez Bondía, M. J., & Cortés Gracia, A. L. (2022). Action research in education: A set of case studies? *Educational Action Research*, *30*(5), 850-864. https://doi.org/10.1080/09650792.2020.1866631

Stewart, J. (2016). *Calculus: early transcendentals 8th edition*. Cengage Learning.

Waheed, S., Pilotti, M. A., & Abdelsalam, H. M. (2024). Am I prepared for Calculus? An action-research study of female students emerging from patriarchy. *Frontiers in Education*, *9*, 1405571.