Journal of Mathematics Education
June 2019, Vol. 12, No. 1, pp. 107-122

https://doi.org/10.26711/007577152790041

Role of Mathematics in Retention of Undergraduate STEM Majors: A Meta-Analysis

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Recruitment and retention of STEM undergraduates have received much attention in recent decades. By virtue of the curriculum, mathematics is more prominent in some STEM majors such as physical science, computer science, engineering, and chemistry. Using a meta-analytic approach, the role of SAT mathematics score, first college mathematics course, and first college mathematics grade in predicting STEM undergraduate retention was investigated. The results of the meta-analysis demonstrate the importance of and need for strong mathematics preparation to be successful in a STEM major. Among the three predictors, first, the mathematics grade had the strongest relationship with STEM major retention. While receiving lower grades in math-intensive courses is common, students who received lower than a C grade in their first-semester mathematics course were highly likely to drop out of their STEM degree program. In order to improve retention rates in STEM majors, there is a need to help students adjust to the new grading system and persevere in the face of academic adversity.

Keywords**:** math-intensive STEM, retention, course taking, grades

The disciplines of STEM (science, technology, engineering, and mathematics) include a wide variety of majors. Some of the STEM majors are known to be math-intensive because they require "mathematics beyond and building upon a full year of single variable calculus" (Bressoud, 2011, p.1). Based on the average number of mathematics courses required, STEM majors such as physical science, computer science, engineering, and chemistry are classified as math-intensive (Musu-Gillette, Wigfield, Harring, & Eccles, 2015). By virtue of the curriculum, mathematics is more prominent in some STEM majors.

Successfully completing required mathematics credits is crucial to progress through math-intensive STEM majors. Students pursuing a bachelor's degree are placed into their first college-level mathematics course based on their high school preparation, and underprepared students are placed in remedial or developmental mathematics courses (Suresh, 2006). The mathematics preparation students receive prior to post-secondary education is critical; students who enter college with higher-level mathematics knowledge and skills are more likely than their peers to succeed within their STEM major (Nite, Capraro, Capraro, Morgan, & Peterson, 2014). Furthermore, failure in college-level mathematics courses has been found to be a critical factor that influences dropout rates within math-intensive STEM majors (Budny, Bjedov, & LeBold, 1997). Specifically, students' high school mathematics preparation, first college-level mathematics course (e.g., remedial course vs. advanced course), and final grade in their first college-level mathematics course have been found to be significant predictors of retention (Tyson, 2011; Van Dyken, 2016). Thus, students' high school mathematics preparation for post-secondary education and their mathematics experiences during their first year of college have a critical role in determining their success and retention in STEM pathways.

The impact of students' first college-level mathematics course on their retention in STEM majors has been well established within previous research; however, the grade they earned within their first college-level mathematics course has received limited attention in relation to retention rates. Given that mathematics emerges as an important predictor of success in STEM majors, there is a need to summarize quantitatively the role of mathematics course-taking and achievement. Hence, the purpose of this meta-analysis was to summarize the role of mathematics course-taking and performance in predicting student retention. The research questions driving the meta-analysis were as follows:

1. What is the relationship between SAT mathematics scores and retention of undergraduate STEM majors?
2. What is the relationship between the first college-level mathematics course taken and retention for undergraduate STEM majors?
3. What is the relationship between the first college-level mathematics grade received and retention for undergraduate STEM majors?

Literature Review

Recruitment and retention of STEM undergraduates have received much attention in recent decades. The emphasis placed on examining matriculation and retention rates within STEM degree programs has grown as the need for well-educated STEM professionals has increased (President's Council on Jobs and Competitiveness, 2011). However, the percentage of bachelors' degrees received in math-intensive STEM majors has remained constant for over three decades (Bressoud, 2011). There is a need to better understand the factors contributing to undergraduate STEM retention.

SAT Scores and STEM Retention

Traditionally, students' high school grade point average (GPA) and SAT or ACT scores have been considered for admission into institutions of higher education. SAT mathematics scores are considered the most important indicator of high school performance (Jin, 2013) and the "best surrogate for

HSGPA [high school GPA]" (Mendez, Buskirk, Lohr, & Haag, 2008, p. 64). Furthermore, research has indicated that higher SAT mathematics scores are correlated with higher probability of students declaring a STEM major, completing a STEM major, and changing from a non-STEM major to a STEM major (Crisp, Nora, & Taggart, 2009; Hielbronner, 2009; Zhang, Anderson, Ohland, & Thorndike, 2004). Moreover, mathematics scores on the SAT have been found to be stronger predictors of STEM major retention, as compared to other majors such as education or business (Hahler & Orr, 2015). As a result, the SAT mathematics score, or the equivalent ACT mathematics score, is considered as a factor when predicting student academic performance in STEM courses and retention in a STEM major.

Even though SAT mathematics scores are considered an important factor in predicting retention within STEM majors, SAT mathematics scores alone may not be able to predict retention of STEM majors. While some researchers have suggested that high school GPA is the only significant predictor of student retention in STEM majors (Johnson, 2012; Lackey, Lackey, Grady, & Davis, 2003), others have argued that the combination of SAT mathematics scores and high school GPA is an effective predictor of retention in STEM majors (Rohr, 2012; Vemulapalli, 2014). However, findings from several previous studies indicated that although the SAT mathematics score was a strong predictor of academic performance in college, it was an inadequate predictor of first-year undergraduate STEM retention (Burton & Ramist, 2001; Jin, 2013; Mattern & Patterson, 2009). Due to the lack of consistency among the research findings, SAT scores should be interpreted with caution.

Mathematics Course and STEM Retention

There are several factors aligned with STEM retention. Successful academic performance and positive experiences during students' freshman year of college (i.e., their first year of college) are considered crucial for ensuring undergraduate retention in STEM majors; however, a majority of the courses a STEM major will take during his or her freshman year of college will be required courses rather than electives. Specifically, in math-intensive STEM degree programs, mathematics and science courses account for nearly half of the freshmen year credit hours (Chen, 2014). The intensive course load freshmen must undertake can be particularly difficult for students who are not prepared for college-level mathematics because they are required to take remedial courses. Mathematics is the most common subject requiring remedial coursework, and this additional coursework may increase the time it takes to complete an undergraduate STEM degree program (Radford, Pearson, Ho, Chambers, & Ferlazzo, 2012). Students taking remedial courses often drop out of STEM programs at higher rates than their peers (Van Dyken, 2016). While remedial courses are important for progressing through STEM majors, starting college with calculus or other advanced mathematics courses increases the probability of success.

The first college mathematics courses adequately prepared students will take are calculus courses. Accounting for approximately 8.3% of the total credit hours required to complete the degree plan (Chen, 2014), calculus is considered a major obstacle to receiving a STEM degree. Researchers have consistently observed that performance in calculus is representative of STEM major persistence (Felder, Forrest, Baker-Ward, Deitz, & Morh,1993; Suresh, 2006). Students who took a calculus course as their first mathematics course in college were significantly more likely to persist in their STEM major (Van Dyken, 2016). However, students who enrolled in calculus during their first semester, but failed the course, were highly likely to leave (Flanders, 2017). Students are required to pass introductory courses to progress through their degree program, but the introductory courses may act as a "barrier" due to their difficulty.

As the academic difficulty level increases, STEM undergraduates are more likely to receive lower grades in college than those they received in high school. Alarmingly, "absolute grades are one of the largest and most persistent factors in the attrition of undergraduates from STEM departments" (Rask, 2010, p.899). Students tend to use grades as a mechanism to gauge their fit within the major (Stinebrickner & Stinebrickner, 2009). Thus, students who receive lower grades in STEM courses may begin to perceive themselves as better suited to a non-STEM major (Ost, 2010). The initial grades students receive during their first undergraduate STEM-related courses in college may significantly influence their inclination to continue or discontinue their journey as a STEM major.

Methods

Literature Search

An article search was conducted using the following databases: ERIC, JSTOR, PsycINFO, and ProQuest Dissertation and Thesis using the Texas A&M library and Google Scholar. The keywords included variants of the following combinations: (undergraduate OR freshmen) AND (science OR technology OR mathematics OR engineering) AND (retention OR persistence OR drop out OR withdrawal). In addition to the preliminary search, an additional manual search of *Journal of Engineering Education*, *Journal of College Student Retention*, *Journal of Higher Education*, *Research in Higher Education,* and *ASEE Conference Proceedings* was performed.

Inclusion Criteria

Only articles published in the past 20 years (between 1998 and 2018) were included. The search results were further narrowed based on the title, abstract, and the entire article. A total of 59 studies, including articles, proceedings, and dissertations were selected based on their title and abstract. After reading each of the 59 studies, 30 studies were found to be relevant to this meta-analysis. The following criterion was used to select articles:

1. Only empirical research articles analyzing primary data were included.
2. Articles were included only if the participants were undergraduate STEM majors with most or all of them in math-intensive STEM majors.
3. Articles were included only if retention of students was studied in relation to mathematics either at the high school or college level.

In case of inadequate information in the article, authors were contacted for the required information. Articles were excluded if the authors did not respond or could not provide the requested information. Finally, 19 articles (9 journal articles, 8 conference proceeding articles, and 2 dissertations) were retained and included in the current meta-analysis (see Table 1).

Data Extraction and Coding

The dependent variable was retention in STEM major. While 9 studies included data on retention of students at the end of their freshman year, 7 studies included data on retention and graduation of STEM undergraduates 4-6 years after their initial enrollment. For 2 studies, retention was only reported after 2 and 3 years. For the purpose of this meta-analysis, studies in which researchers reported retention rates at the end of freshman or sophomore years were grouped together as "early retention", and studies in which researchers reported retention after junior or senior years, or degree attainment, were grouped as "later retention". From each study, the percentage retention of students in a STEM major by their first mathematics course and their first mathematics grade was extracted, if available. Because calculus is considered a "barrier" course for undergraduate STEM majors, groups were defined by the following in terms of their first mathematics course: (1) students taking courses below calculus, such as developmental math and pre-calculus, (2) students taking calculus or above, such as Calculus II. For course grade, groups were defined by (1) students receiving A, B, or C in their first mathematics course, (2) students receiving D, F (fail), or W (withdraw) in their first mathematics course.

Mean SAT quantitative score and the standard deviation were extracted for both students who remained in their STEM degree program (referred to in this study as STEM *persisters*) and those who did not (referred to as *non-persisters*). Alternately, if group means were not reported, point biserial correlation between STEM major retention and SAT quantitative score was extracted. Other study characteristics such as (a) sample size, (b) gender distribution, (c) cohort year, (d) STEM major distribution, (e) retention measure, and (f) publication type were also coded.

Adjustments and Estimates

Whenever data were presented in the form of graphs instead of tables, WebPlotDigitizer (Rogatgi, 2011) was used to extract data from graphs. For two studies, the researcher of the present meta-analysis relied on the authors' descriptions of the data to obtain the best possible estimate for missing data. Specifically, Lougheed (2015) reported grade distribution only for the pre-calculus course because the other mathematics courses followed a similar distribution; therefore, the same grade distribution was assumed for all mathematics courses. In addition, based on the description in Gardner, Pyke, Belcheir, and Schrader (2007), the distribution of first mathematics course taken was assumed to be the same for students who enrolled and those who persisted in the program.

For pre-college variables such as SAT/ACT, if the scores were presented as intervals (e.g. 200-400), the means of the intervals were calculated based on Sandon (1961). On two occasions, ACT scores were scaled to equivalent SAT scores using the equi-percentile method (Dorans, Lyu, Pommerich, & Houston, 1997). The equi-percentile method ensures the same rank ordering of scores within the sample. If the standard deviation of SAT scores was not reported for the sample, the population standard deviation of 100 was assumed.

Data Analysis

All effect size calculations and conversions were done according to Lipsey and Wilson (2000). Based on the percentage retention, effect sizes by course and grade were calculated. If the point-biserial correlation was reported for ACT/SAT scores, they were converted to standardized mean difference. All effect sizes were converted to Hedge's *g* effect size and corrected for sample size. As the number of studies by predictor were small, a fixed effects model was used. The average effect size was calculated and a homogeneity test performed.

Results

Observations from a total of 75,455 participants were included in the current meta-analysis. Sample sizes of studies varied from 129 to 35,347 (see Table 1). Early retention rates ranged from 50.39% to 79.58%, with an average of 73.68%. Late retention rates ranged from 30.79% to 86.43%, with an average of 77.11%. The overall retention rate was 76.75%.

SAT Mathematics Scores and STEM Undergraduate Retention

There was a consistent positive relationship between SAT scores and STEM retention, with the exception of the findings from Palm and Thomas (2015), in which no relationship between these variables was reported. The standardized mean difference in SAT scores between persisters and non-persisters varied from 0 to 0.74 (see Figure 1). The average effect size was 0.36. Specifically, a moderator analysis with retention type revealed that the effect size for early retention (0.47) was statistically significantly ($p < 0.05$) larger than the effect size for later retention (0.36). The effect sizes were statistically significantly heterogeneous. However, rejection of the homogeneity assumption may be an artifact of large sample sizes. When studies with large sample sizes, Ackerman, Kanfer, and Calderwood (2013) and Min et al. (2011) were excluded, the average effect size increased to 0.52. After the exclusion of large sample sizes, the effect sizes were still found to be statistically significantly heterogeneous. Additionally, there was no statistically significant (p > 0.05) difference between the average effect size reported in the journal articles (0.42) and that reported in the conference proceedings (0.36).

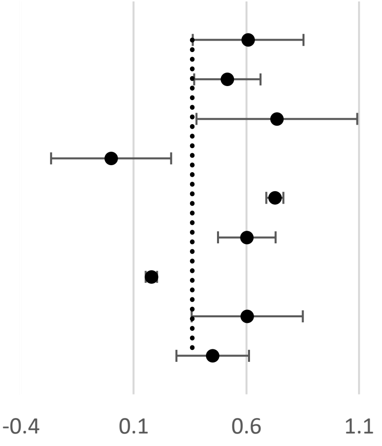
Table 1

Summary of Studies included in the Meta-analysis

Study	Publication Type	Major	N	Retention Variable	Predictor
Ackerman, Kanfer, & Calderwood (2013)	Journal article	STEM	23448	graduation	Course, SAT
Callahan & Belcheir (2017)	Journal article	STEM	1139	1-year retention	Grade, Course
Cambel (2012)	Dissertation	STEM*	310	1-year retention	Grade, Course
Cassady & Mulvenon (2009)	Proceeding	Engineering	336	1-year retention	Grade
DeJong & Langenderfer (2012)	Journal article	Engineering	445	graduation	Course
French, Immekus, & Oakes (2005)	Journal article	Engineering	1000	4year retention	SAT
Gardner, Pyke, Belcheir, & Schrader (2007)	Proceeding	Engineering	337	1-year retention	Grade, Course
Hall et al. (2013)	Proceeding	Engineering	289	2-year retention	SAT
Honken & Ralston (2013)	Journal article	Engineering	289	1-year retention	Course
Leuwerke, Robbins, Sawyer, & Hovland (2004)	Journal article	Engineering	844	1-year retention	ACT
Lougheed (2015)	Dissertation	STEM	3777	graduation	Grade, Course
Middleton et al. (2014)	Proceeding	Engineering	615	4-year retention	Grade, Course
Min, Zhang, Long, Anderson, & Ohland (2011)	Journal article	Engineering	35347	graduation	SAT
Moses et al. (2011)	Journal article	Engineering	129	1-year retention	SAT
Palm & Thomas (2015)	Proceeding	Engineering	239	1-year retention	Course, SAT
Reynolds (2008)	Proceeding	Engineering	266	4-year retention	ACT
Scott, Tolson, & Huang (2009)	Journal article	STEM	630	3-year retention	SAT
Van Dyken, Benson, & Gerard (2015)	Proceeding	Engineering	4040	1-year retention	Grade, Course
Yoon, Imbrie, & Reed (2014)	Proceeding	Engineering	1975	graduation	Grade, Course

Note. * Excluding engineering majors.

	Study	% Weights	Hedge's *g* effect sizes
Early retention	Hall et al. (2013)	0.67%	
	Leuwerke et al. (2004)	1.87%	
	Moses et al. (2011)	0.32%	
	Palm & Thomas (2015)	0.57%	
Late retention	Ackerman et al. (2013)	28.17%	
	French et al. (2005)	2.49%	
	Min et al. (2011)	63.67%	
	Reynolds (2008)	0.67%	
	Scott et al. (2009)	1.57%	



Test for Heterogeneity: Chi-squared = 594.45, df = 8, $p < 0.05$
$I^2 = 98.65\%$

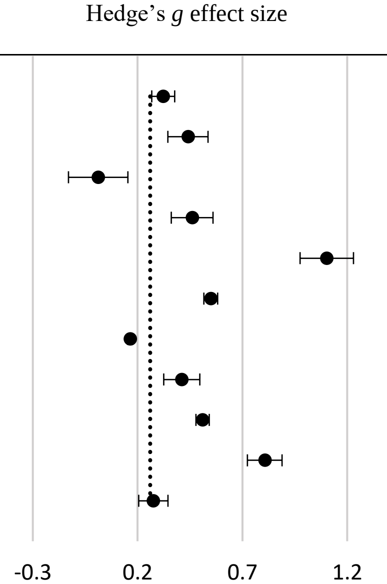
Figure 1. *Forest plot for the effect of SAT mathematics scores on STEM undergraduate retention. The dotted line represents the overall effect size (0.36).*

First Mathematics Course and STEM Undergraduate Retention

When separated by the first mathematics course taken, students whose first college-level mathematics course was calculus or another upper-level mathematics course were more likely to persist with an average effect size of 0.26 (see Figure 2). The effect sizes were statistically significantly heterogeneous. Specifically, the average effect size for early retention (0.5) was statistically significantly ($p < 0.05$) higher than the effect size for later retention (0.22). The early retention rate for students starting with calculus or higher was 83.33% as compared to 63.91% retention for students enrolled in courses that are mathematically less advanced than calculus. Late retention rates for students starting with a lower-level mathematics course (70.92%) were not drastically different from students starting with calculus or higher (72.16%). About 70% of the weight was assigned to Ackerman et al. (2013) due to the study's large sample size. When this study was excluded from the analysis, the average effect size increased to 0.5. Then, the average late retention rate of students starting with a calculus course or higher was 54.89%, and the retention rate for students starting with courses lower than calculus was 30.92%.

Additionally, publication type was a moderator with journal articles (0.18) reporting a statistically significantly ($p < 0.05$) lower effect size as compared to dissertation and conference publications (0.53).

	Study	% Weights
Early retention	Callahan & Belcheir (2017)	3.36%
	Cambel (2012)	1.10%
	Gardner et al. (2007)	0.50%
	Honken & Ralston (2013)	1.02%
	Palm & Thompson (2015)	0.62%
	Van Dyken et al. (2015)	9.30%
Late retention	Ackerman et al. (2013)	69.26%
	DeJong & Langenderfer (2012)	1.36%
	Lougheed (2015)	9.95%
	Middleton et al. (2014)	1.47%
	Yoon et al. (2014)	2.07%



Test for Heterogeneity: Chi-squared = 826.58, df = 10, $p < 0.05$
$I^2 = 98.8\%$

Figure 2. *Forest Plot for the effect first mathematics course on STEM undergraduate retention. The dotted line represents the overall effect size (0.26).*

First Mathematics Grade and STEM Undergraduate Retention

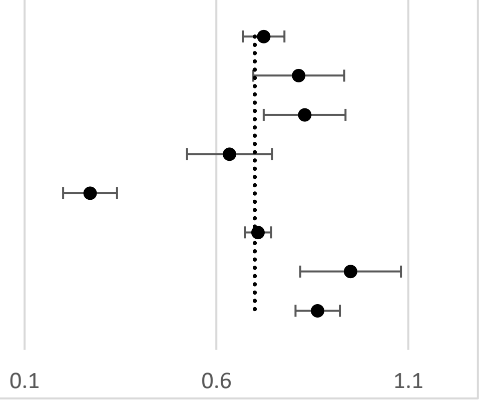
When separated by the first mathematics grade, students who obtained a grade of C or higher were more likely to persist with an average effect size of 0.70 (see Figure 3). The average effect size for early retention (0.62) was statistically significantly lower than the effect size for later retention (0.76). The early persistence rate of students who received an A, B, or C grade (80.76%) was significantly higher than the persistence rates of students who received a D, F, or W grade (51.97%). Similarly, the late persistence rate of students who received an A, B, or C grade (54.08%) was significantly higher than the persistence rate of students who received a D, F, or W grade (16.48%). The effect sizes were statistically significantly heterogeneous. A subgroup analysis by publication type was not realistic because most of the articles reporting first-course grade were conference proceedings.

Limitations

STEM retention is a heavily researched subject, and a variety of predictors and retention variables are used in literature. As a result, the number of studies included in this meta-analysis is small, and journal articles comprise only about 50% of the published works. Further, a publication bias between published and unpublished literature was found for first mathematics course. As a majority of the studies in which first mathematics grade was used as a predictor are unpublished, the effect size may be biased. There is a need for more empirical research to explore the role of initial grades in STEM retention.

	Studies	% Weights
Early retention	Callahan & Belcheir (2017)	17.19%
	Cambel (2012)	3.59%
	Cassady & Mulvenon (2009)	4.44%
	Gardner et al. (2007)	4.10%
	Van Dyken et al. (2015)	10.21%
Late retention	Lougheed (2015)	42.46%
	Middleton et al. (2014)	2.93%
	Yoon et al. (2014)	15.08%

Forest Plot



Test for Heterogeneity: Chi-squared = 146.25, df = 7, $p < 0.05$
$I^2 = 95.21\%$

Figure 3. *Forest Plot for the effect first mathematics course on STEM undergraduate retention. The dotted line represents the overall effect size (0.7).*

Discussion

Mathematics performance is considered an important predictor of success in STEM majors. A meta-analytic approach was used to investigate the value of SAT mathematics score, first college mathematics course, and first college mathematics grade in predicting STEM undergraduate retention. On average, the strongest predictor of retention was first mathematics grade, followed by SAT mathematics score and first college mathematics course.

Researchers of STEM retention have primarily concentrated their research on academic factors such as SAT scores and students' first college mathematics course while frequently overlooking the affective components of transitioning to college. Students within math-intensive STEM majors have been found to receive relatively lower grades when compared to peers in non-STEM majors (King, 2015). Moreover, incoming STEM majors are often ill-equipped to deal with lower grades or academic challenges (Marra, Rodgers, Shen, & Bogue, 2012). As students generally use introductory course grades to assess their fit in the major, receiving lower grades may lead to discontinuing the major (Main, Mumford, & Ohland, 2015). Results from this meta-analysis reinforce the importance of initial college grades. Students' first mathematics grade was found to have the strongest relationship with STEM retention. Irrespective of the first college mathematics course taken, students who made a C or higher in their first mathematics course were more likely to persist.

However, students who received similar grades might have had vastly different experiences during their first semester of college due to variables such as different classes/class structure, instructors, peers, or other factors. Additional research is required to understand the role of first semester experiences in relation to initial grades in student retention. There is a need to understand how students process their academic challenges at the university level. Further insight into this matter may help educators at both the K-12 and post-secondary level better understand how to prepare and foster their students' knowledge and ability to adapt within academic contexts.

While mathematics preparation (i.e., SAT mathematics scores and first college mathematics course) is considered important predictor of retention, its impact on early retention was significantly larger than on later retention. Specifically, the impacts of placing students in remedial or developmental mathematics courses have been controversial. Previous reviews have indicated that these programs lower the rate of attrition (Lesik, 2007). Similarly, results of this meta-analysis suggest being placed in a mathematics course lower than calculus does not place students at a disadvantage. While students placed in remedial or developmental mathematics courses may leave at a higher rate during their first or second year, the 4-year retention or graduation rates only differed marginally. As students progressed through the major, their initial preparation seemed to have a smaller effect on retention. This trend may signify the role of other non-academic characteristics such as study skills, self-efficacy, motivation, or personality on retention (Moses et al., 2011; Robbins et al., 2004). In order to improve retention rates of STEM undergraduates, there is a need to understand the role of non-academic and affective factors during their journey through the major.

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