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Vertical assessment of math competency among freshmen and sophomore engineering students

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Vertical assessment of math competency among freshman and sophomore engineering students

Abstract

In recent years, many studies have found that lack of preparation in mathematic skills among freshman engineering students posed serious problems for retention and graduation of these students. Multiple initiatives have been ongoing to address the problem including revising the engineering mathematic contents and delivery, utilizing interactive tools and online learning environment, implementing new and better ways to impart math skills to the students, motivating students on improving their math skills, etc. One of the important issues that must be known before successfully addressing the math competency problem among engineering students is to collect and analyze their math preparation and math skills throughout their four years of engineering study. The present paper presents assessment data of math skills among freshman and sophomore engineering students. The paper identifies areas of common weaknesses among these students and discusses whether there are relationships between math preparation and student demographic background.

Introduction

Knowledge and application of mathematics, physical sciences, and engineering sciences are essential for engineering students. In recent years, many studies[1-3] have found that lack of preparation in mathematic skills among entering freshman engineering students posed serious problems for retention and graduation of these students. Actually, it has long been recognized that math preparation of incoming freshman students is not sufficient for university study, especially for Science, Technology, Engineering and Mathematics (STEM) disciplines. As a result, many universities offer bridge or remedial courses to address the issue for incoming engineering students. For example, since 1995, Virginia Tech's Center for the Enhancement of Engineering Diversity (CEED) established and implemented a summer bridge program for pre-enrolled freshman students entering the College of Engineering in the subsequent fall[1].

In addition to bridge courses, there are numerous efforts to improve math preparation of engineering students in many different avenues. Multiple initiatives[2,4-14] have been implemented to address the problem including revising the engineering mathematic contents and delivery, utilizing interactive tools and online learning environment, implementing new and better ways to impart math skills to the students, motivating students on improving their math skills, etc. For example, Berlin Institute of Technology offered a freshman course called "Early Bird" where students have the opportunity to take the mathematics courses of the first semester (Calculus I for Engineers and Linear Algebra for Engineers) before they are enrolled in the university[6]. In Georgia Institute of Technology, the school in collaboration with four local school systems is teaching sophomore-level calculus via distance learning to students who have exhausted the math offerings in their high school[7]. Other efforts to improve students' learning of mathematic include use of computer course[8], Gaming and interactive learning[9,10], projects[11], real world and engineering applications [12,13], MediaWiki[14], and many more.

Motivation and Objectives

Most of the studies and remedies mentioned in the previous section are directed towards freshman engineering students. However, continuous assessment and evaluation of engineering students on their math preparation throughout their study is essential for success in any engineering discipline. In addition, it is imperative to identify problematic areas of mathematics for students in different levels of their engineering studies so that they may be addressed in relevant engineering courses. The first step in addressing the math competency of engineering students is to collect and analyze their math preparation and math skills.

Based on the works of ASEE Mechanics Division, mechanic readiness test was developed and tested in 1978[15] and since then several studies[16-19] have been conducted on mechanics readiness of engineering students. However, most of these studies were limited to evaluating math readiness for the first engineering mechanics class, Statics. Therefore, the authors decided to assess and evaluate math skills of freshman and sophomore students in three courses: Introduction to Engineering which was a freshman course for engineering students in fall 2011 and 2012 semesters, Dynamics which was a core course for Mechanical, Civil and Industrial engineering students in spring and summer semesters of 2012, and Surveying which was a core course for Civil engineering students in fall 2012 semester. Only results from Introduction to Engineering and Dynamics courses will be included in this paper.

The main objectives of the paper are

- to assess and evaluate math preparation of freshman and sophomore engineering students
- to identify math topics that are most problematic to freshman and sophomore engineering students, and
- to determine possible relationships between demographics and math preparation/performance of freshman and sophomore engineering students

The demographic information of students, detail information on the math tests, and summary of test results and conclusions are given in the following sections of the paper.

Freshman Demographic Results

Math preparation test of the incoming freshman class was conducted in the fall semester of 2011 and 2012 academic years. The questionnaire has two parts: demographic and math. The demographic survey questions the gender, race, number and identification of completed math courses in high school. The results of the demographic survey of students from fall 2011 semester are shown in Figure 1.

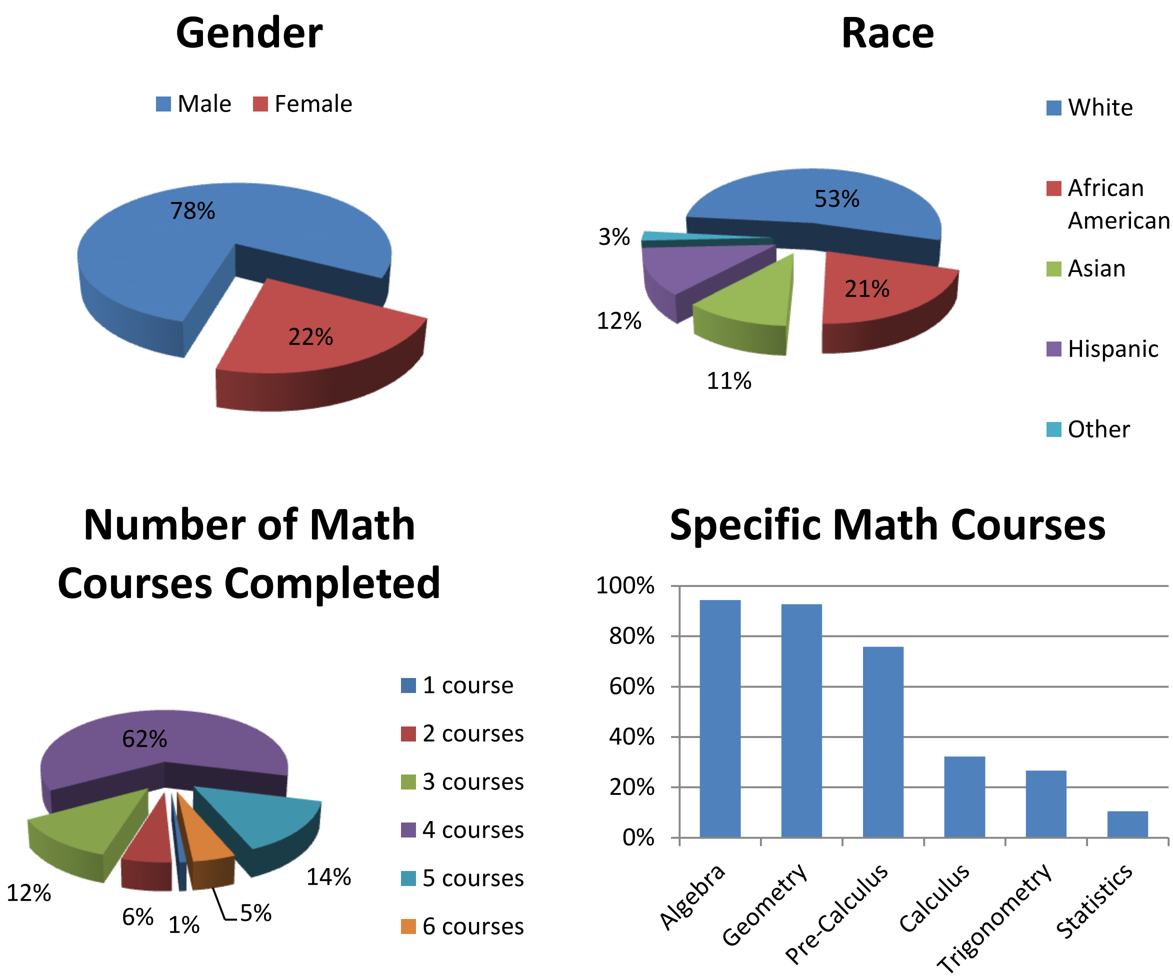


Figure 1 Results of demographic survey of freshman students from fall semester of 2011

Figure 1 shows that the composition of freshman class is 78% male and 22% female students. This gender composition closely follows typical makeup of male and female students in engineering and STEM disciplines. In terms of race, 53% are white whereas African American, Asian and Hispanic make up 21%, 11% and 12% of the students respectively. In recent years, the percentage of underrepresented minority students pursuing engineering at Lamar University have grown significantly and that fact can be clearly seen in Figure 1. Majority of students (more than 80%) have completed 4 or more math courses at high school while only 7% of students have completed 2 or fewer math courses at high school. Number of math courses completed at high school is one of the critical parameters in predicting math preparation of freshman students as discussed later in the paper. More than 90% of students completed algebra and geometry courses while 75% of the students already completed Pre-Calculus course at the high school. Those students completed Calculus, Trigonometry and Statistic course made up only 32%, 27% and 10% of the total students respectively.

Freshman Math Results

The math test consists of 20 questions on a range of mathematic topics covered in typical high school mathematic courses such as algebra, geometry, and trigonometry. Materials from similar tests[15, 18] were considered in designing the topics and specific questions of the test. Each math topic with the corresponding number of questions in parenthesis is given below.

- Algebra (6)
- Geometry (7)
- Trigonometry (5)
- Probability and statistics (2)

The time limit of 50 minutes was given to complete both demographic survey and math test. The test was a closed book and was given in the fall semesters of 2011 and 2012 with the sample size of 124 and 120 students respectively. In this paper, only the results from fall semester of 2011 were discussed. The overall results of the math test are given in Table 1. The average score is close to 60% with a rather large spread in data represented by the standard deviation of 20%. In many of the math tests for freshman class in the literature, the expected score is 70 to 75% but the average score is only 58% in Table 1 indicating that math preparation of freshman class of fall 2011 is not satisfactory. In addition, the low average score with a large standard deviation indicates that the retention of math topics from high school is quite low for this particular freshman class.

Table 1 Overall math results of freshman students from fall semester of 2011

Statistical Parameter	Results
Sample size	124
Maximum score	19 (95%)
Minimum score	1 (5%)
Average score	11.7 (59%)
Standard deviation	4.05 (20%)

Table 2 provides more details on the results of the tests as it lists the description of each question together with the percentage of students who score the question correctly. Table 2 shows that 2 algebra, 2 geometry and 1 probability questions received low scores of 40% or less. In particular, question number 3, an interpretation of a graph, received the lowest score of 20% and question number 9, determination of the volume of a prism, received the second lowest score of 30%. It should be noted that 3 out of 6 algebra questions involve reading and interpreting a graph because graphical representation is one of the important requirements for a prospective engineering student. Students scored relatively low for 2 out of 3 graphical questions with 20% for question 3 and 40% for question 5. Question 6 involves a two-step determination of an equation of a line and it also received a low score of 35%. Among the geometry questions, two lowest scores, 30% and 35%, are for questions that require determination of volumes of a prism and a cylinder respectively. It seems that majority of the students do not recall the correct formula for calculating the volume of a three-dimensional solid from their high school geometry course. The other lowest score comes from one of the probability question, question 19, which requires use of both trigonometry and probability to answer the question correctly. Within the limited sample size and results of the present paper, it may be concluded that math questions involving multiple steps or interpretation pose great challenges to the freshman students of fall 2011.

Table 2 Results of individual math questions of freshman students from fall semester of 2011

Question Number	**Topic**	**Correct Score in percentage**
1	Definition of a function graphically (Algebra)	75%
2	Nested functions (Algebra)	55%
3	Interpretation of a graph (Algebra)	**20%**
4	Lines (Algebra)	75%
5	Interpretation of graph in percentage (Algebra)	40%
6	Equation of a line (Algebra)	**35%**
7	Equation of a circle (Geometry)	80%
8	Equation of a circle (Geometry)	60%
9	Volume of a prism (Geometry)	**30%**
10	Interpretation of graph (Geometry)	50%
11	Volume of a cylinder (Geometry)	**35%**
12	Area of a triangle (Geometry)	65%
13	Right triangle (Geometry)	85%
14	Complex number (Pre-Cal)	55%
15	Zero of polynomial (Pre-Cal)	80%
16	Value of a trigonometric function (Trigonometry)	80%
17	Trigonometry of a circle (Trigonometry)	80%
18	Identity in trigonometry (Trigonometry)	45%
19	Probability	**35%**
20	Probability	75%

The scores of male and female students are similar in average score as well as standard deviation. White students scored much higher than all other racial groups except the group that did not identify their race (other group). It is interesting to note that Hispanic students have higher average score than the other minority groups (African American and Asian). The most striking result of Table 2 is that the average score of students who completed four or more math courses in high school are much higher than those with fewer high school math courses. It may be concluded that students with more math courses in high school in general may be better prepared mathematically for an engineering study. Figure 2 shows the average score of students as a function of the number of math courses completed at high school.

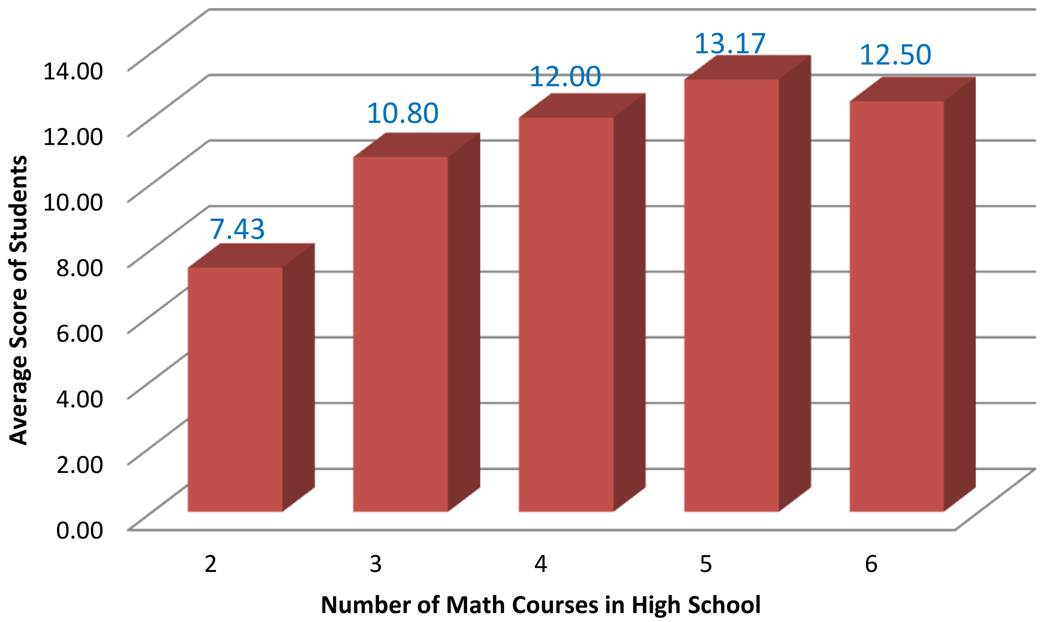


Figure 2 Average score as a function of number of math courses completed in high school for freshman students of fall 2011 semester

Table 3 Results of relationship between the math score and demographics of students

Demographic Item		**Results**	
		Average Score	***Standard Deviation***
Gender	Male	11.8 (59%)	4.2 (21%)
	Female	11.3 (56%)	3.6 (18%)
Race	White	13.4 (67%)	3.4 (17%)
	African American	9.1 (45%)	3.9 (20%)
	Asian	8.7 (44%)	3.7 (18%)
	Hispanic	10.7 (54%)	3.2 (16%)
	Other	13.7 (68%)	1.2 (6%)
Number of Math Courses	2	7.4 (37%)	3.9 (19%)
	3	10.8 (54%)	4.9 (24%)
	4	12 (60%)	3.6 (18%)
	5	13.1 (66%)	4.5 (22%)
	6	12.5 (63%)	3.3 (16%)

Engineering Math Curriculum at Lamar University

In the engineering curriculum at Lamar University, there are six required math courses: MATH 2413 Calculus and Analytic Geometry I, MATH 2414 Calculus and Analytic Geometry II, MATH 3435 Calculus and Analytic Geometry III, MATH 3328 Linear Algebra, MATH 3301 Differential Equations, and one statistics course. All engineering students are required to complete one statistics course during their study but it is not relevant to the present study and therefore the detail information on the statistic course is not included in Table 4. Each math course, the semester it is offered, and the topics covered in the course are listed in Table 4.

Table 4 Required Math Courses and their Contents

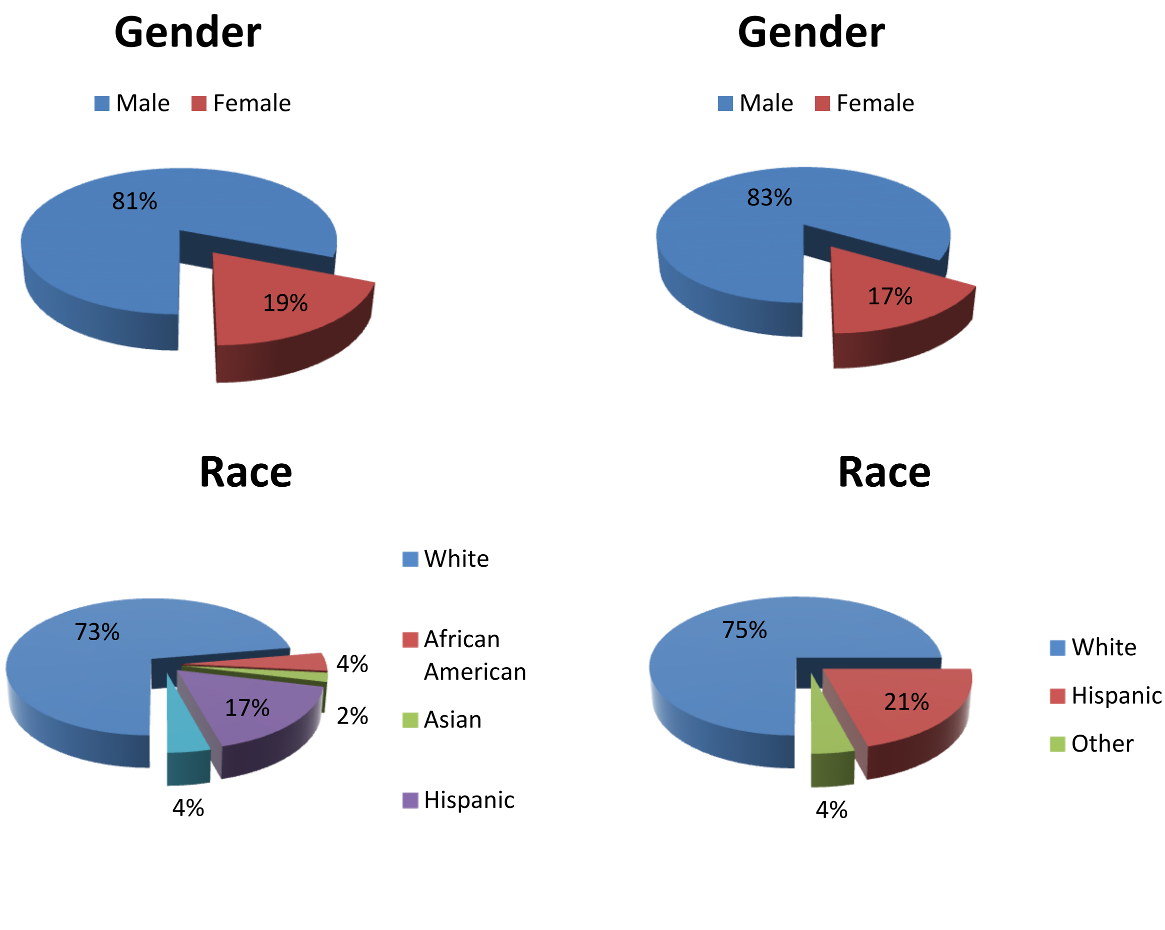
Math Course	Semester	Contents
MATH 2413 Calculus and Analytic Geometry I	Fall, freshman	Limits, Derivatives, Applications of derivatives, Integrals, Applications of integrals
MATH 2414 Calculus and Analytic Geometry II	Spring, freshman	Integration Techniques, Applications of integrals, Parametric Equation and Polar Coordinates, Sequences and Series, Vectors
MATH 3435 Calculus and Analytic Geometry III	Fall, sophomore	Three Dimensional Space, Partial Derivatives, Applications of Partial derivatives, Multiple Integrals, Line integrals, Surface Integrals
MATH 3328 Linear Algebra	Fall, sophomore	Systems of Equations and Matrices, Determinants, n-Euclidean Space Vector Space, Eigen values and Eigen vectors
MATH 3301 Differential Equations	Spring, sophomore	First Order ODE, Second Order ODE Laplace Transform, Systems of DEs, Series Solutions, Higher Order DE, Boundary Value Problems and Fourier Series, PDE

MEEN 2302 Dynamic Class

MEEN 2302 Dynamics course is offered in the spring and summer semesters of the sophomore year and many students in the dynamics class have already completed at least 3 of 5 required math courses and many may be taking the remaining two math courses (Calculus III and Differential Equations) concurrently with Dynamic course. Dynamic course consists of mainly sophomore and junior students but some seniors are also allowed to take class. Lamar University classifies students with their number of credit hours completed at the university so some students in Dynamic course are classified as junior but they actually are in the sophomore year of their engineering study.

Sophomore Demographic Results

The demographic survey contains questions related to race, gender, class standing, number and identification of university math courses taken or are taking at the time of the survey. The demographic results from Dynamic course for the spring and summer semesters of 2012 are shown in Figures 3 and 4.



(a) (b)

Figure 3 Results of demographic survey of students from Dynamic course of (a) spring and (b) summer semesters of 2012

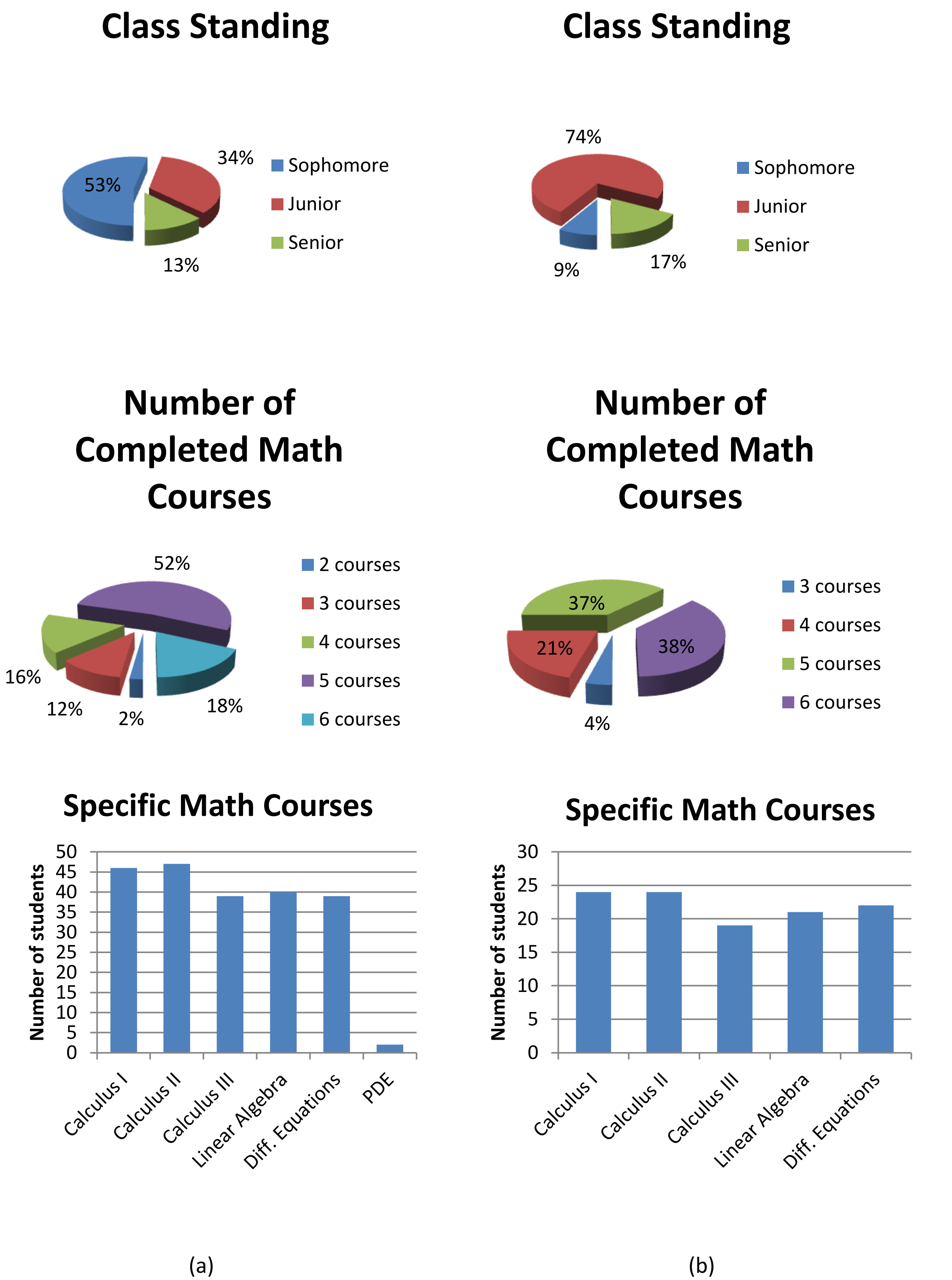


Figure 4 Results of demographic survey of students from Dynamics course of (a) spring and (b) summer semesters of 2012

Demographic results showed that the class composition was similar with 80% male and 20% female students in both semesters. In terms of race, the majority of students in both semesters are white followed by Hispanic students. At Lamar University, students were classified according to the credit hours completed at the University as mentioned above, and as a result, the survey results of class standing showed that sophomore and junior made up the majority of the class (more than 80%) with the rest being senior students. Majority of the students completed 3 or 4 math courses out of 5 required math courses.

Sophomore Math Results

The test consists of 13 questions covering a range of topics deemed essential to succeed in Dynamic course.

- Derivatives and integrals
- Vectors
- Systems of equations
- Matrices
- Determinants

Similar to the development of freshman math test, math contents and questions from similar studies[15-19] were considered in designing the math test for sophomore students. The students are given 50 minutes to complete both demographic survey and math test. The test was a closed book and was given in the spring and summer semesters of 2012 with the sample size of 48 and 24 students respectively. The math results for individual students and the relationships between math and demographic results are discussed next. The overall test results were given in Table 5. Looking at Table 5 shows that the average score for both samples are similar at about 60%. Surprisingly, similar average scores were obtained in much earlier test of Snyder[15] and recent studies of Neghaban[16] and Mehta[17].

Table 5 Overall math results of students from Dynamics course of spring and summer semesters of 2012

Statistical parameter	**Results**	
	Spring 2012	***Summer 2012***
Sample size	47	24
Maximum score	13 (100%)	11 (85%)
Minimum score	2 (15%)	2 (15%)
Average score	7.5 (58%)	7.7 (59%)
Standard deviation	2.75 (6%)	2.3 (10%)

Detail results of the math test for Dynamic class were shown below in Table 6 with description of each question and the percentage of students that scored the question correctly.

Table 6 Results of individual math questions of Dynamic course from spring and summer semesters of 2012

Question Number	**Topic**	**Correct Score**	
		Spring 2012	Summer 2012
1	System of linear equations (2)	94%	92%
2	Determinant (2 x 2)	62%	75%
3	Matrix multiplication (2x2)	**34%**	**38%**
4	Derivative of trigonometric functions	53%	63%
5	Slope of a curve/ derivative	83%	75%
6	Derivative of power functions	57%	67%
7	Dot product of two vectors	51%	**33%**
8	Cross product of two vectors	**21%**	**17%**
9	Dot product/ angle between vectors	**26%**	**13%**
10	Derivative of mixed functions	72%	92%
11	Definite integral of power functions	72%	75%
12	Definite integral of trigonometric functions	72%	71%
13	Matrix form of system of linear equations	55%	58%

Table 6 shows consistent results between the two samples as the lowest scores for both samples are for questions 3, 8, and 9. In In addition, question 7 also received the lowest score for the summer 2012 semester. In both samples, question 1 received the highest scores whereas question 10 also received highest score in the summer 2012. The lowest scores came from questions related to vector and matrix operations, such as dot and cross products of vectors, and matrix multiplication. The other question related to the topic of matrix, question 13, also received a low score of around 60%. In general, students performed well in questions related to derivatives and integrals so Calculus topics related to differentiation and integration may not be problematic for the students considered in the present paper. From Table 6, it can be seen that the two samples have similar scores for the majority of the questions indicating that majority of the students in general have difficulty handling matrix and vector operations.

Table 7 shows the relationships between demographic and math test scores of the students. Average scores of female students were higher than those of male students whereas Hispanic students had similar score (slightly lower score in spring semester but higher score in summer semester) to those of white students. It is a reversal of the results from freshman class where white students received higher average score among different racial groups. Sophomore and senior students received higher average scores than those of junior students who were the majority of students in the class. In terms of math courses, the students that completed more courses (5 and 6 courses) had average scores lower than those who took only 4 courses which was a surprising result. This may be attributed to the retention of previous course materials as students that took more math courses might have taken math classes required for Dynamic course much earlier and therefore might not retain those earlier materials. There are no statistical differences among the average scores of students who have already taken Calculus I, II, III, Linear Algebra, and Differential Equations courses.

Table 7 Results of relationship between the math score and the demographic of students from Dynamic course of spring and summer semesters of 2012

Demographic Item		**Average**		**Standard Deviation**	
		Spring	Summer	Spring	Summer
Gender	Male	7.45	7.55	2.88	2.46
	Female	7.89	8.25	2.2	1.26
Race	White	7.65	7.12	2.91	2.42
	Hispanic	7.38	9	2.33	1.49
	African American	5.5		3.54	
Class Standing	Sophomore	8.04	9.5	2.41	0.71
	Junior	6.88	7.35	3.3	2.47
	Senior	7.17	8.4	2.48	2.07
Number of Math Courses	3	6.6		2.88	
	4	7	8.8	1.41	1.64
	5	8.35	7.4	2.74	2.51
	6	6.75	7.3	3.2	2.55
Specific Math Course	Cal I	7.43	7.67	2.7	2.3
	Cal II	7.53	7.67	2.75	2.3
	Cal III	7.95	7.37	2.61	2.39
	Linear Algebra	7.68	7.62	2.91	2.44
	Diff. Equations	7.87	7.68	2.81	2.4

Conclusions and future work

The paper reports the results of math preparation of freshman in the Introduction to Engineering class and sophomore/ junior students in the Dynamic class at Lamar University over the span of fall 2011 to summer 2012. The math test also contains demographic survey of students such as gender, race, class standings, number of math courses taken, etc. The results are presented in both tabular and graphical format that include demographic representation of students, overall math scores, and scores of individual math question, and relationship between various demographic information and math score. The major conclusions based on the limited sample of students in the present study are as follows:

1. Math preparation of freshman students for engineering study is not satisfactory based on the overall low average score (~ 60%) as well as low scores on some specific math questions.
2. Freshman students have difficulty handling math questions involving multiple steps or interpretation of graphical information.
3. Math performance of freshman students improves significantly for students who completed more math courses at high school.
4. Math preparation of sophomore/junior students in Dynamics course is not satisfactory based on the overall low average score (~ 60%) as well as low scores on some specific math question.
5. Sophomore/junior students have difficulty handling math questions involving matrix and vector operations such as dot and cross products of vectors and matrix multiplication.
6. Average scores of female students are similar to those of male students in both Introduction to Engineering and Dynamic courses so gender may not be a barrier for female students to pursue STEM disciplines such as engineering.
7. Average scores of African American students are slightly lower than those of White and Hispanic students in both Introduction to Engineering and Dynamic courses.

Future work may involve continuous evaluation of math preparation of freshman and sophomore students in the coming academic years as well as investigation of present results to determine how math preparation of students correlate to their performance in the actual course such as Dynamics. Based on the results of the present paper, the authors concurred that continuous assessment and evaluation of engineering students on their math preparation throughout their undergraduate study is essential. Therefore, more assessment and evaluation on higher math topics such as differential equations and statistics will be conducted in junior and senior level engineering courses.

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