Math-Proficiency Program for New Engineering Students

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***Abstract* – It has been well recognized that many entry-level engineering students struggle with studying college-level math courses due to their lack of explicit experiences and opportunities reviewing and integrating basic mathematical fundamentals and principles that they have studied during their high school education. In response, the Marquette University – Opus College of Engineering has developed the math-proficiency program (in the areas of precalculus) to help new engineering students prepare for and study college-level math courses (such as calculus and differential equations) which are fundamental to engineering education. After running the math-proficiency program for the last five years, it was discovered that many new engineering students are clearly able to recognize and find the areas and topics in precalculus that they are weak and need to improve during their first semester at college. The math-proficiency test analysis results show that student performance in the course *Freshman Engineering Discovery 1*, which is taken during their freshman year at college, for the students who scored well above the minimum point level consistently maintained high marks throughout college-level courses, while some students who scored well below the set point somewhat struggled in studying college-level courses.**

Index Terms – college-level math courses, math-proficiency, new engineering students, precalculus

INTRODUCTION

According to the Wikipedia online directory [1], "*Engineering is the application of mathematics, empirical evidence and scientific, economic, social, and practical knowledge in order to invent, innovate, design, build, maintain, research, and improve structures, machines, tools, systems, components, materials, and processes.*" Mathematics plays a key role in engineering. Whereas science deals with nature, namely things that can be observed and measured (seen, felt, heard, smelled, tasted, weighed, etc.), mathematics deals with the mind. The mind is known only to its owner; it produces thoughts and thoughts cannot be seen, felt, tasted, smelled or otherwise observed and measured. Mathematics is about logic. Indeed, there is no agreement that mathematics is a science at all. But using the word "science" loosely, mathematics is the science of consistency. Mathematics is not connected to the physical world in any particular way; rather it is all about what is in our minds. Mathematics provides the framework for thinking logically.

Since most engineering core courses require engineering students to be able to use proper scientific fundamentals (laws and theories) and mathematical principles to solve and analyze a number of virtual, imaginary (from most engineering textbooks), and real engineering problems in various disciplinary areas and fields, all engineering students are required to take and study a series of science and math courses (such as physics, chemistry, biology, college-level calculus, linear algebra and differential equations among others) as prerequisite courses before taking and studying core engineering courses.

It is a well-known fact that most (entry-level) engineering students struggle with studying college-level math courses primarily due to their lack of explicit experiences in using/applying basic mathematical principles to scientific and engineering problems during their high school education [2].

In order to help entry-level engineering students prepare for and study college-level math courses, many institutions offer various remedial on-campus math courses and/or related online math courses, while providing proper college-level credits for taking these courses [3]. However, a number of issues exist in running, managing and maintaining these remedial and/or online math courses, such as students' availability to attend or participate in the on-campus or the online remedial courses/classes, the administrative issue of how to assign/provide proper college-level credits to the students, and other concerns.

In order to overcome some of the issues described above and help the new engineering students prepare for and study college-level math courses, the Marquette University – Opus College of Engineering has developed the math-proficiency program for all incoming engineering students registered in the *Freshman Engineering Discovery 1* course [4], which is offered every fall semester. Students are provided a math study packet (developed by the author with about 500 exercise problems) about one month before the beginning of the first semester and are encouraged to solve as many math problems (in the areas of precalculus) in the math study packet. Also, students are asked to solve a math-proficiency homework assignment with fifty problems selected from the math study packet, to be submitted by the end of the first week of the first semester. To assist students, a number of review sessions (run by the course TAs) are

offered to help the students who have been determined to be weak and/or unfamiliar with some topics. Finally, students are asked to take a math-proficiency test during the semester after the graded math-proficiency homework is returned. The students who score below a designated minimum point level are required to take a series of make-up tests until they are able to pass the test.

This paper shows some of the direct and indirect measures (or analysis results) of the effectiveness of running the math-proficiency program through the *Freshman Engineering Discovery 1* course. The analysis has been performed by tracking student academic performance for the last five years.

MATH-PROFICIENCY PROGRAM

I. Math-Proficiency Study Packet

The math-proficiency study packet in the areas of precalculus along with precalculus formulas for algebra, geometry and trigonometry has been developed for entry-level engineering students to review and study the basics of precalculus before they start taking and studying college-level calculus courses. About five hundred exercise problems are prepared in the math-proficiency study packet, in which an answer key for the odd-numbered problems is provided for the students to check their answers/solutions. Table I lists the eight chapter topics or areas in the math-proficiency study packet. At the beginning of each chapter, an introductory section with a number of simple exercise problems are prepared for the students to check and even confirm their understanding of the fundamentals related to the chapter topic. Additional exercise problems are attached after the introduction section for the students to solve more problems to strengthen their math skills in the chapter topic.

TABLE I
PRECALCULUS TOPICS USED FOR THE MATH-PROFICIENCY PROGRAM AND STUDY PACKET

1.	Arithmetic/Algebraic Operations
2.	Graph Recognition
3.	Inequalities
4.	Trigonometric Functions
5.	Exponentials/Logarithms
6.	Geometry
7.	Powers, Polynomials, and Rational Functions
8.	Series, Continuity, and Limits

Since most entry-level engineering students are familiar with the areas and topics included in the math-proficiency study packet from their high school education, they are encouraged to use their high-school math textbooks and related references, including online tutorials, as reference materials to obtain a deeper understanding of the math fundamentals.

Figure 1 shows the distributions of the exercise problems in each topic within the math-proficiency study packet. It can be seen that more problems are assigned in topics 1, 4 and 5 (shown in Table I) because of the importance of using these topics/areas in engineering mathematics based upon the author's experience teaching engineering mathematics and/or related courses.

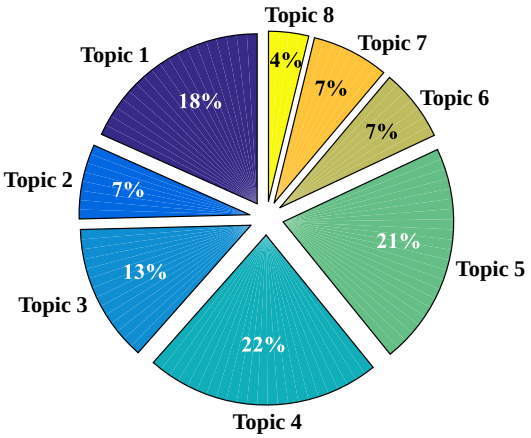

FIGURE 1
PROBLEM DISTRIBUTIONS IN THE MATH-PROFICIENCY STUDY PACKET (TOPICS SHOWN IN TABLE I)

TABLE II
LIST OF BASIC PRECALCULUS FORMULAS

ALGEBRA
• Quadratic formula, special production and factoring formula
• Exponents and radicals, binomial theorem
• Inequalities and absolute value, means, sequences, exponentials and logarithms
(Area and Volume) FORMULAS FROM GEOMETRY
• Triangle, rectangle, parallelogram, trapezoid, circle, circular sector and circular ring
• Rectangular box, sphere, right circular cylinder, right circular cone, frustum of a cone, prism
CONIC SECTIONS & PLANE GEOMETRY
• Basic equations for parabola, ellipse and hyperbola
• Similar triangles and congruent alternate interior angles
ANALYTIC GEOMETRY
• Distance formula, equation of a circle, slope of a line, graph of a quadratic function
• Point-slope form of a line, slope-interception form of a line, interception form of a line
TRIGONOMETRY
• Trigonometric functions of acute angles, arbitrary angles and real numbers
• Special right and oblique triangles
• Laws of cosines and sines
• Fundamental identities between trigonometric functions
• Formulas for negatives, cofunction, double and half angles, angle addition and subtraction
• Product-to-sum and sum-to-product formulas

In addition to the math-proficiency study packet, a table-format handout of basic precalculus formulas for algebra, geometry and trigonometry is prepared for the students to recognize the importance of using them to solve many precalculus problems. Table II shows the list of basic precalculus formulas in the handout. It is strongly recommended for the students to memorize (if possible) these formulas before they try to solve the exercise problems in each topic within the math-proficiency study packet. It is also recommended that the students create their own formula tables if needed.

II. Math-Proficiency Homework

Since the math-proficiency program runs through the *Freshman Engineering Discovery 1* course, the students' performance on the math-proficiency homework assignment and test is considered a part of the course grade. Fifty problems selected from the math-proficiency study packet are assigned as homework for the students to solve and submit by the end of the first week of their first college semester. These problems are selected from the even-numbered problems from the math-proficiency study packet, which were not included in the answer key. For each homework problem, the students cannot provide just an answer but must show how they obtained their answer.

Figure 2 shows the distributions of the homework problems of each topic shown in Table I. It can be seen that similar problem distributions are used as the math study packet shown in Figure 1.

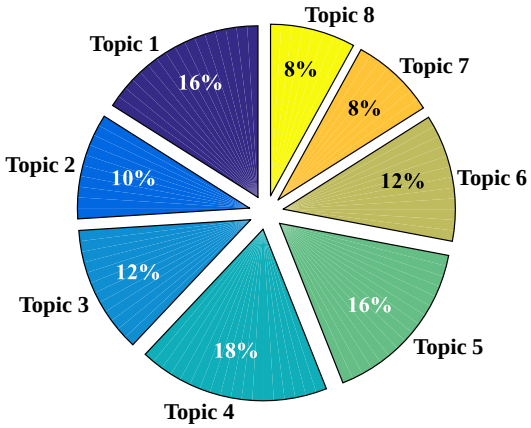

FIGURE 2
PROBLEM DISTRIBUTIONS IN THE MATH-PROFICIENCY HOMEWORK (TOPICS SHOWN IN TABLE I)

III. TA's Math Review Sessions

About fifteen undergraduate-student teaching assistants (TAs) are hired to assist running the *Freshman Engineering Discovery 1* course. All of them took the *Freshman Engineering Discovery* courses when they were freshmen and they are taking more advanced college-level math courses, such as a series of college-level calculus and differential equations courses.

Before the semester starts, all TAs are asked to review and solve the topics/problems included in the math-proficiency study packet. During the first two weeks of the semester, three to four course TAs are assigned to offer math review sessions every night (Monday through Friday) for about three hours to help the freshman students solve problems within the math-proficiency study packet and homework. Table III shows the course TA's math review session schedule. During the first week of the semester, the course TAs cover two topics or chapters every day. During the second week of the semester, after returning back the graded math-proficiency homework assignment to the students, the review sessions are still offered to help students correct mistakes in solving exercise problems in the homework.

TABLE III
TA'S MATH REVIEW SESSIONS SCHEDULE

Week #1 – Reviewing Precalculus Topics 1 - 8			
Tuesday	Wednesday	Thursday	Friday
Topics 1 & 2	Topics 3 & 4	Topics 5 & 6	Topics 7 & 8
Week #2 – Reviewing Specific Topics			

IV. Math-Proficiency Test

All incoming engineering students registered in the course, *Engineering Discovery 1*, are required to take the math-proficiency test during the third week of the semester. The closed-book test, which allows for the use of a hand-held calculator, has fifty problems to be solved during one class period (one hour and fifty minutes). Figure 3 shows the distributions of the problems within the math-proficiency test which is similar to those for the math-proficiency homework shown in Figure 2.

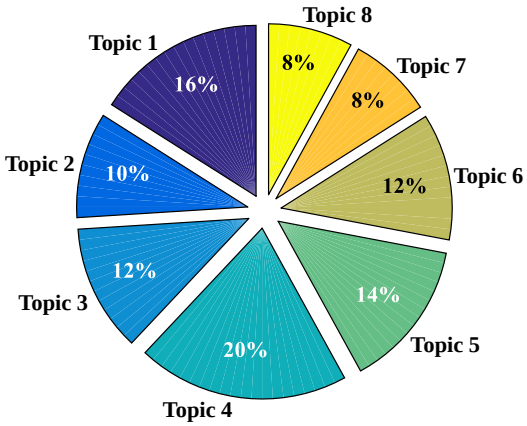

FIGURE 3
PROBLEM DISTRIBUTIONS IN THE MATH-PROFICIENCY TEST (TOPICS SHOWN IN TABLE I)

Figure 4 shows the distributions of the math-proficiency test scores (averaged over the last five years) normalized by the highest score in the area of the graph recognition. It can be seen that most freshman engineering students are relatively weak in the area of trigonometric function. It can be considered that their weakness is primarily due to the (engineering) students' reliance on hand-held calculators to solve trigonometric function related math problems (without analyzing them) during their high school education.

The students who score below a designated minimum point level are asked to retake the math-proficiency test (until they pass) in order to improve their basic math skills in precalculus during the first semester of their freshman year.

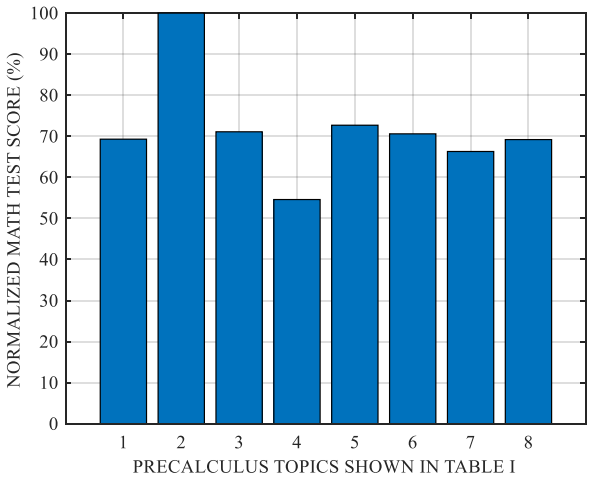

FIGURE 4
NORMALIZED MATH-PROFICIENCY TEST SCORE DISTRIBUTIONS IN EACH AREA OF PRECALCULUS

MATH PROFICIENCY AND COURSE PERFORMANCE ANALYSIS

Table IV shows the overall structure and content of the *Freshman Engineering Discovery 1* course in which various types of class activities are included. The details about the course can be found in the author's previous work [4].

TABLE IV
OVERALL COURSE STRUCTURE AND CONTENTS OF THE COURSE - FRESHMAN ENGINEERING DISCOVERY 1

Math-Proficiency Program	
Engineering Graphics Fundamentals & Computer-Aided Design (CAD) Practice	Introduction to Engineering and Engineers & Multidisciplinary Department Module Sessions
Graphics & CAD Team Project – Poster Exhibition & Competition	

In order to investigate and analyze the effectiveness of running the freshman math-proficiency program through the *Freshman Engineering Discovery 1* course, the relationship between the students' math-proficiency (in precalculus area) and their course performance has been obtained by tracking student work for the last five years.

Figure 5a shows the distributions of the course accomplishment (above 90%) for the students who scored various levels of math-proficiency test scores. It can be seen that more than 95% of the students (whose math-proficiency test scores are above 90%) and about 90% of the students (whose math-proficiency test scores are between 80 and 89%) obtained high course performance above 90%. It also shows that more than 75% of the students (whose math-proficiency test scores are between 60 and 79%) obtained high course performance (above 90%). It was also found that about 45% of the students (whose math-proficiency test scores were below 60%) were even able to attain higher course performance (above 90%). It is believed that even though some of them failed the first math-proficiency test, they continuously studied to pass the test, resulting in obtaining higher course performance.

Figure 5b shows that about 90% of the students (whose math-proficiency test scores were above 80%) and about 80% of the students (whose math-proficiency test scores were above 60%) achieved high course performance (above 90%).

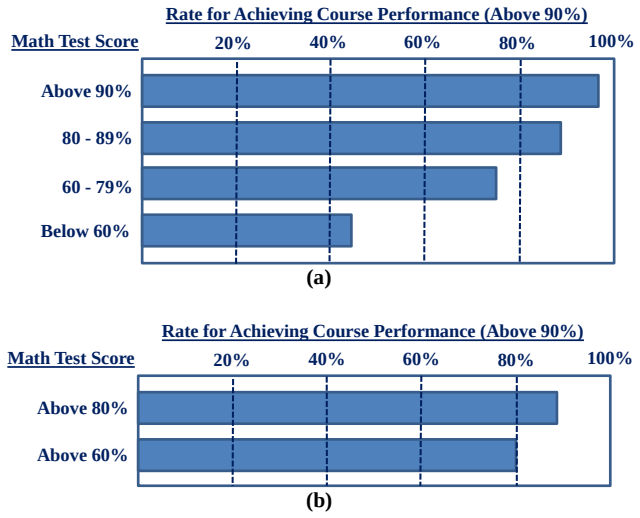

FIGURE 5
STUDENTS' COURSE PERFORMANCE (ABOVE 90%) WITH THEIR MATH-PROFICIENCY TEST SCORES

Figure 6 shows the distributions of the students' course discontinuation rate (averaged over the last five years) after finishing their first semester at college. The average class retention rate is about 88%. It can be seen that about 20% of the students whose math-proficiency test scores are below 60% discontinue studying engineering.

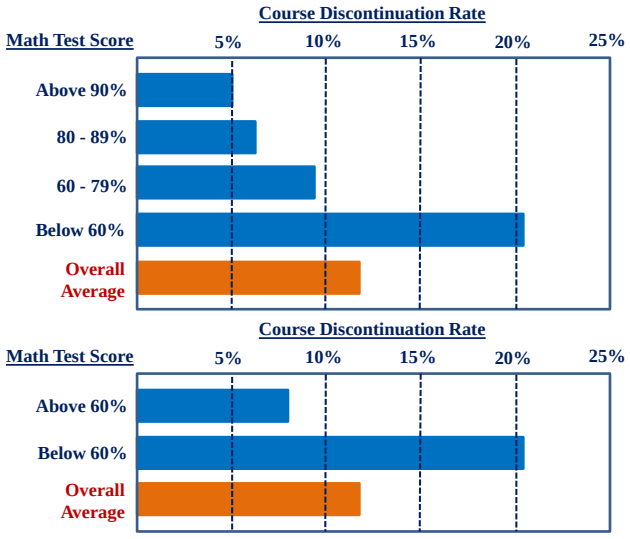

FIGURE 6
DISTRIBUTIONS OF COURSE DISCONTINUATION RATE BASED ON THE MATH-PROFICIENCY TEST SCORES

SUMMARY AND CONCLUSIONS

After running the math-proficiency program for the incoming engineering students for more than five years, it was discovered that many new engineering students are clearly able to recognize and find the areas and topics in precalculus that they are weak and need to improve. It has also been suggested for the students whose math-proficiency test scores are below the minimum point level to spend additional time to study and improve their math skills through various alternative methods and tools such as tutorials and online programs.

The analysis shows that the academic performance (explicitly, during their freshman year at college) for the students who scored well above the minimum point level consistently maintain high marks, while some students who scored well below the set point somewhat struggled in studying college-level courses. Evidence supports the finding that this program helps new engineering students study the college-level math courses (such as a series of calculus and differential equations courses) which are fundamental to engineering education.

REFERENCES

[1] Wikipedia online directory, https://en.wikipedia.org/wiki/ Engineering.

[2] Kim, S., "Engineering Retention and Student Math Preparedness," 6th *First Year Engineering Experience (FYEE) Conference, Session F1C,* College Station, TX, August 7-8, 2014.

[3] Borganonkar A., Kam M., Candermark S. and Hou E., "Engineering Math Summer Boot Camp to Help Students Succeed in Remedial Courses," 7th *First Year Engineering Experience (FYEE) Conference, Session T2B,* Roanoke, VA, August 3-4, 2015.

[4] Park, H., "Freshman Engineering Discovery Courses at Marquette University – College of Engineering," *6th First Year Engineering Experience (FYEE) Conference, Session F1A*, College Station, TX, August 7-8, 2014.

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