
AC 2011-1209: OPENING THE ENGINEERING GATEWAY: CAN DIFFERENTIATED INSTRUCTION HELP PREPARE OUR UNDERSERVED STUDENTS?

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Myra W. Curtis is the Retention Support Specialist for the Clarence M. Mitchell, Jr. School of Engineering at Morgan State University. Ms. Curtis received her B.S. degree in Mathematics from Morgan State College in 1970 and a Master of Engineering degree in Industrial Engineering from Morgan State University, May 2010. Ms. Curtis spent twenty years in industry in designing, programming, and testing software systems on various platforms for the Department of Defense (DOD), National Aeronautics and Space Administration (NASA), and the Department of Transportation (DOT). She has taught mathematics and computer science in the public and private sector. As the Retention Support Specialist, Ms. Curtis provides support to the University and School of Engineering retention strategies. She also works closely with the School of Engineering student leaders in developing and coordinating outreach initiatives for pre-college students.

Opening the Engineering Gateway: Can Differentiated Instruction Help Prepare Our Underserved Students?

Introduction

In more recent times, there has been a concerted effort to put a strong emphasis on education to increase the numbers of eligible participants entering into the science, technology, engineering, and mathematics (STEM) workforce of the future. While the overall number of students enrolling in STEM degreed programs and receiving engineering degrees in is steadily increasing, the ability to attract and retain qualified students from traditionally underserved and underrepresented communities has been problematic. This disparity is in many cases due to an inadequate primary and secondary education infrastructure. Until this problem is adequately addressed, there are many students who are being prevented from contributing to our national need for innovation. Furthermore, it seems that not enough is being done at the postsecondary level to improve the readiness of our underserved student population.

Research at our institution from 1994 through 2009 on freshmen engineering cohorts indicate that the initial math course placement correlates highly with the likelihood of being retained in engineering¹. Those students who started with Calculus 1 (Math 241) or Comprehensive Pre-calculus (Math 141) graduated at a rate twice as high as those who started with Pre-calculus 1 (Math 113). Alternatively, the cohorts that started in basic math (MATH 106) take an average of over seven years to graduate. Calculus I is the first mathematics course that counts towards an engineering degree in many colleges and university STEM programs. Many schools are facing increasing enrollments from students such as these. Studies such as How People Learn²: Brain, Mind and School Expanded Edition ³Adding It Up⁴, Strengthening the Linkages Between the Sciences and Mathematical Sciences⁵ have shown that with focused intervention strategies many of the students can enjoy productive academic and professional experiences. Similar to the United States another argument can be made that there are regions in the world that have huge pools of nontraditional students that could be actively engaged in providing engineering goods and services of benefit to their infrastructure and society⁶.

While an overarching goal of the efforts at our institution is to prepare and retain students in STEM and to improve the preparation of students for careers in engineering, the strategy employed in this work is to improve the pedagogy and student experiences in lower division undergraduate engineering programs, through collaborations among engineering, education, psychology, language arts, and mathematics faculty. This is accomplished by: developing faculty who possess and incorporate the most effective pedagogical techniques in the classroom, using in depth psychological strategies that consider self efficacy, integrating technology, where appropriate, leveraging differentiated instruction and formative assessment and using a coordinated and integrated strategy. This paper reveals our findings on reducing the time it takes to prepare our students for Calculus I, henceforth improving retention statistics, through promoting teaching and learning through differentiated instruction and the powerful Dimensions of Learning (DOL) pedagogy⁷. The Dimensions of Learning is a theoretical framework in which students acquire and integrate knowledge, extend and refine knowledge, use knowledge meaningfully, learn to think critically, learn to think creatively, and learn to regulate behavior.

Methodology

In order to increase the number of students entering the engineering profession, one approach was to examine and improve the calculus preparatory courses by infusing innovative pedagogical methods and technology to motivate students and increase their success rate. Additional effort was taken to expose the faculty to some of the most effective methods to help students learn. The DOL strategies fill the necessary knowledge gaps of entering engineering students over an accelerated and intensive period to ensure that they can be calculus-ready within their first year of college.

An important instructional method employed in this work is the use of differentiated instruction. Differentiated Instruction is an instructional concept that maximizes learning for all students—regardless of skill level or background. It is based on the fact that in a typical classroom, students vary in their: academic abilities, learning styles, personalities, interests, background knowledge and experiences, and levels of motivation for learning.

The University requires a mathematics placement test (ACCUPLACER™) for SEM students, and advisors enroll students in the mathematics course in which the student places. Over the last two years, based on the placement examination administered to all incoming students, less than 5% of SEM students tested as being ready calculus 1 for the first semester. Figure 1 shows the possible path that students may take to enter into the calculus stream. They may place into Math 106, Math 113, Math 141 or Math 241. The proposed sequence allows more flexibility to get to calculus I in a shorter amount of time. First, the Foundations of Mathematics online course is a preventative measure to ensure a significant portion of incoming freshmen place above the MATH106 level. Secondly, the two part MATH113-MATH114 sequence is replaced with a two part ENGR101-ENGR102 sequence. The first part, ENGR101, is strategically taught with differentiation so that a student can test directly into calculus at any time. For those students needing extra time, the second sequence, ENGR102 allows for that.

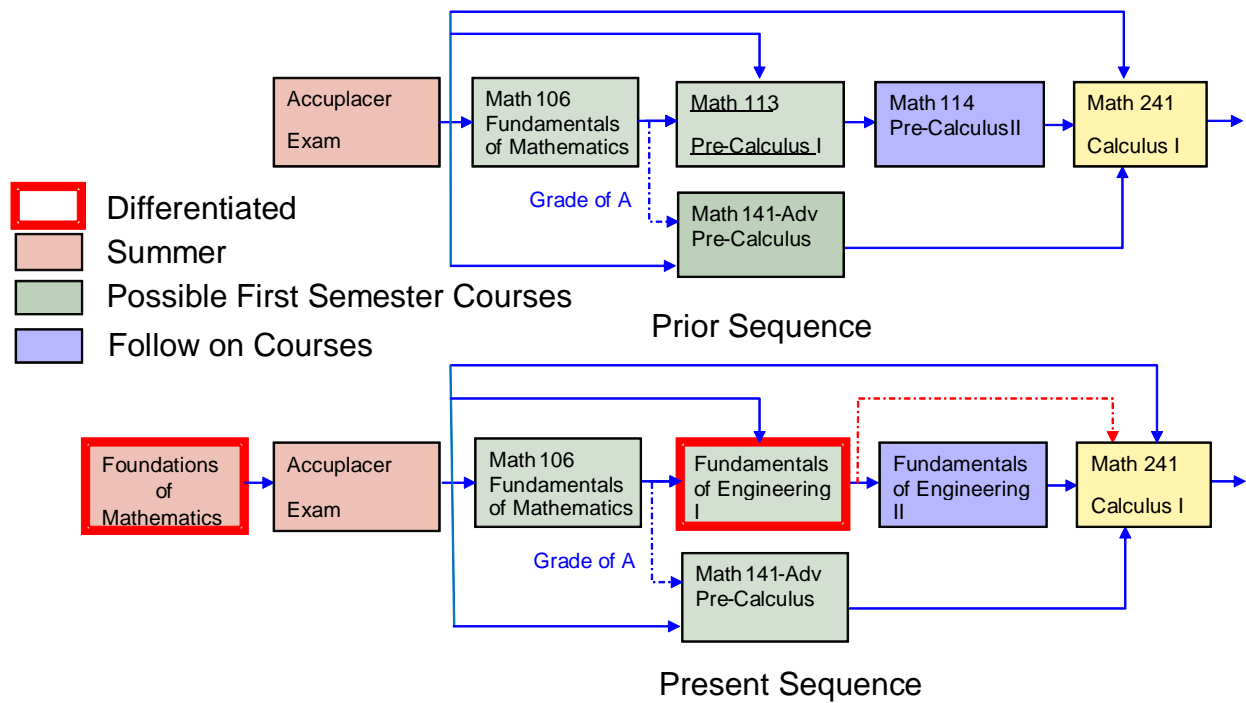


Figure Error! No text of specified style in document. Prior (Top) and Present (Bottom) Flow Diagram of Incoming Freshmen Mathematics Sequence.

Foundations of Mathematics Online Pre Freshman Mathematics Course

The “Foundations of Mathematics” (FOM) course was implemented in the summer of 2000 to help address the problem of the increasing number of first-year engineering students who are being placed in remedial math courses such as Math-106 (Basic Algebra). The goal of the online course is twofold: its first goal is to improve the math skills of entering freshmen engineering students; the second goal of the online course is to prepare the students for the university mathematics ACCUPLACER™ placement exams. Having an online math course has helped facilitate that task by allowing prospective engineering students refresh and improve their mathematics skills. The use of online courses offers the most flexible and cost-effective way of reaching out to prospective college students through their respective high school science and mathematics teachers.

Fundamentals of Engineering (FOE) Course

This course is a part of a seamless approach to learning math related STEM skills starting at the pre freshman level through the use of a FOM/ Fundamentals of Engineering (FOE)/Pre-calculus/calculus course sequence. The Fundamentals of Engineering course features a “dynamic” syllabus tailored to meet the individualized instructional needs of each student predicated on a battery of pre diagnostic tests administered at the beginning of class. Once the students are placed in the appropriate math group, we employ a proven educational pedagogy

that consists of a combination of the Dimensions of Learning instructional framework, differentiated instruction., Engineering Performance Tasks to keep the engineering students engaged and focused in their math courses, and differentiated instruction assisted by reverse lecturing techniques and the use of software technology such as ALEKS⁸ (Assessment and Learning in Knowledge Spaces). Similarly, the student’s progress is continually monitored and measured against the anticipated outcome and not an arbitrary grade assignment. The individually tailored dynamic syllabus will serve as a roadmap and assessment tool that will guide the student to successful mastery of the required math skills.

ALEKS is web-based software designed to facilitate students’ learning and performance in various fields including mathematics. The primary use of ALEKS in this project is to support differentiation in a cost effective manner. It is used for homework assignments, quizzes, assessments, and exams. Students are given the incentive to advance at their own pace and are motivated by their teachers to do so. Engineering Performance Tasks are embedded within the pre-calculus learning process, continuously and repeatedly, in order to demonstrate how mathematical methods, techniques, and skills are essential to the study and practice of engineering. An example of the DOL mapped course outcomes aligned with a performance task is shown in the table below.

Table 1 Sample DOL course outcomes matching

Task/Concept	Declarative Knowledge	Procedural Knowledge	Performance Task #
1. Real Numbers	<ul style="list-style-type: none"> a. Know the types of numbers that make up the real number system (natural numbers, integers, rational numbers, and irrational numbers). b. Understand what is meant by a one-dimensional space. c. Understand the relationship between interval notation and inequality notation. d. Understand the concept of the absolute value. 	<ul style="list-style-type: none"> a. Classify a real number as a natural number, an integer, a rational number, or an irrational number. b. Construct a real number line as well as plot points and intervals on a real number line. c. Represent sets on the real number line in interval notation and inequality notation. d. Find the distance between two real numbers on the real number line. 	Performance Task No. 1
2. The Function Concept	<ul style="list-style-type: none"> a. Know what a function is. b. Understand function notation. 	<ul style="list-style-type: none"> a. Determine if a relationship given in the form of a table of values is a function. b. Evaluate functions (including piecewise-defined functions) at numerical and algebraic expressions. c. Find the domain of a function algebraically. 	Performance Task No. 2

Table 2 Sample performance task relating to the above units of study

Pre-Calculus Engineering Performance Task # 2
Math Concept: Unit 1 - The Function Concept, Graphs of Functions

I. Engineering Topic

Sizing pipes for a sewer line based on the required flow volume.

II. Learning Outcomes (DOL 2)

Declarative knowledge

The student understands:

- The function notation.
- How to prepare a graph of a function
- How to use the vertical line test to determine if a curve is a graph of a function.

Procedural knowledge

The student is able to:

- Evaluate functions of numerical and algebraic expressions.
- Sketch the graph of a function using point plotting.
- Solve applied problems using functions

III. Thinking or Reasoning Processes

DOL 3: Extend and Refine

Classifying expressions as functions.

Using *inductive reasoning* to draw and support conclusions about values computed.

Using *deductive reasoning* to determine if all computed values were valid in the context of the problem.

Abstracting a pattern of information when selecting required size of pipe.

DOL 4: Use Knowledge Meaningfully

Decision making in selecting the correct pipe size.

Problem solving using the data provided.

IV. Description of Performance Task

Engineering Context

Wastewater is removed from homes and commercial establishments using sanitary sewers. Sewers are large pipes which generally flow partially full downhill under gravity. Sewer pipes from communities merge into larger ones as the wastewater is taken to wastewater treatment plants. The design and operation of sewer pipes is complicated by infiltration by storm water inflow through loose manhole covers and ground water inflow at breaks in the lines due to tree roots, etc. The quantity of water infiltrating the system must be estimated. However preliminary sizes are assigned based on typically known water use patterns.

V. Rubric

Criteria (or elements)	0 (Novice) Makes an effort. No Understanding.	1 (Apprentice) OK, good try. Unclear if student understands.	2 (Practitioner) Very good. Clear. Strong understanding.	3 (Expert) Wow. Awesome! Excellent understanding.
1) Understands the function notation.	Cannot identify a function by its notation.	Understands the notation for only one side of the expression	Clearly understands the structure of the notation.	Clearly understands and can explain the structure of the notation. Offers correct examples.
2) Understands how to prepare a graph of a function	Cannot explain how to prepare a graph of a function	Understands some but not all of the method used to prepare a graph of function	Clearly understands the method used to prepare a graph of a function	Clearly understands the method used to prepare a graph of a function. Offers correct examples.
1) Follows procedure to evaluate functions of algebraic expressions	Is unable to procedure to evaluate functions of algebraic expressions	Evaluates functions of algebraic expressions correctly some of the time	Correctly evaluates functions of algebraic expressions	Correctly evaluates functions of algebraic expressions and show all steps
2) Follows procedure sketch the graph of the function	Is unable to sketch the graph of the function correctly	Can only partially graph the function correctly. Has trouble with other parts.	Can correctly sketch the graph of the function.	Can correctly sketch the graph of the function. Provides graph title, labels axes, supplies units.
3) Follows procedure to solve applied problems using functions	Cannot solve problem that applies function concept	Makes errors when solving problem using functions	Correctly solves applied problems using functions by following procedure	Correctly solves applied problems using functions by following procedure. Shows all steps.
Communication	Student could not explain what he was attempting to do.	Student explained some of what was done. Could not explain all of the solution correctly	Student clearly explained how the problem was solved. Clearly understood the function concept and how to use it.	Student clearly detailed how the problem was solved. Clearly understood the function concept. Understood how to plot and use the graph.

Findings/Discussion

The Foundations of Mathematics online program has had a total of 187 participants during the past 6 summers (Summers 2003-2009), and the results indicate (see Figure 2) that only 24% of all the students who completed the online course placed in Math-106, versus 43% of students who did not participate in any summer mathematics review (N=508). These results are very encouraging. For the Math 241 (calculus) and Math-141 (pre-calculus) courses, the FOM online math students had a successful placement rate that was more than twice as high as the students who did not participate in any summer enrichment program.

The results show that if students are given the opportunity to review their math concepts properly, and they take the initiative to do so, they can do extremely well on their placement exams. It also means that they have a higher chance of graduating in 4-5 years. The results are very significant for the School of Engineering because the majority of the students who graduate in 5 years or less start out in either Math-241 or Math-141.

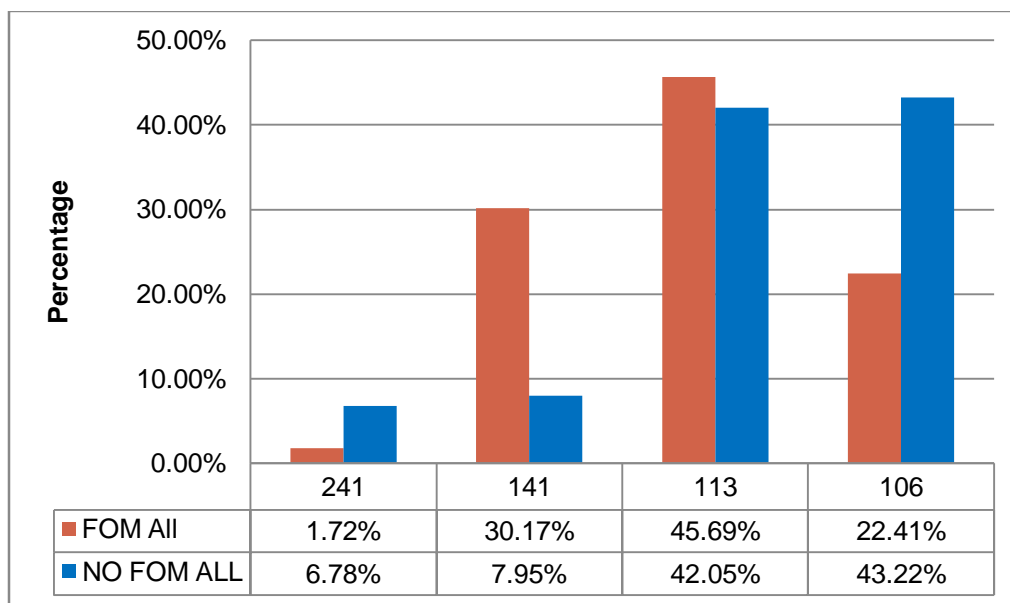


Figure 2 FOM online program math placement comparison summary

The Fundamentals of Engineering course had 34 cohorts. The grade distribution is shown in Figure 3. Placement into Calculus I was determined by a score of 70% or better on the comprehensive final exam. Forty percent (40%) successfully passed this exam and were allowed to enroll in Calculus I. Also of significance is the 82% pass rate as compared to 62% (N=53) for the conventional unmodified course sections. The influence of the Foundations of Math online preparation is also evident. The peak of the grade distribution for the FOM students is in the “A” performance range were as the peak grade distribution for the students that did not participate

falls within the “C” performance range. The PACE cohorts were placed in this section as a result of not successfully completing the resident program during the summer. Of those PACE students participating, 63% were recovered and placed directly into Calculus I after the first semester.

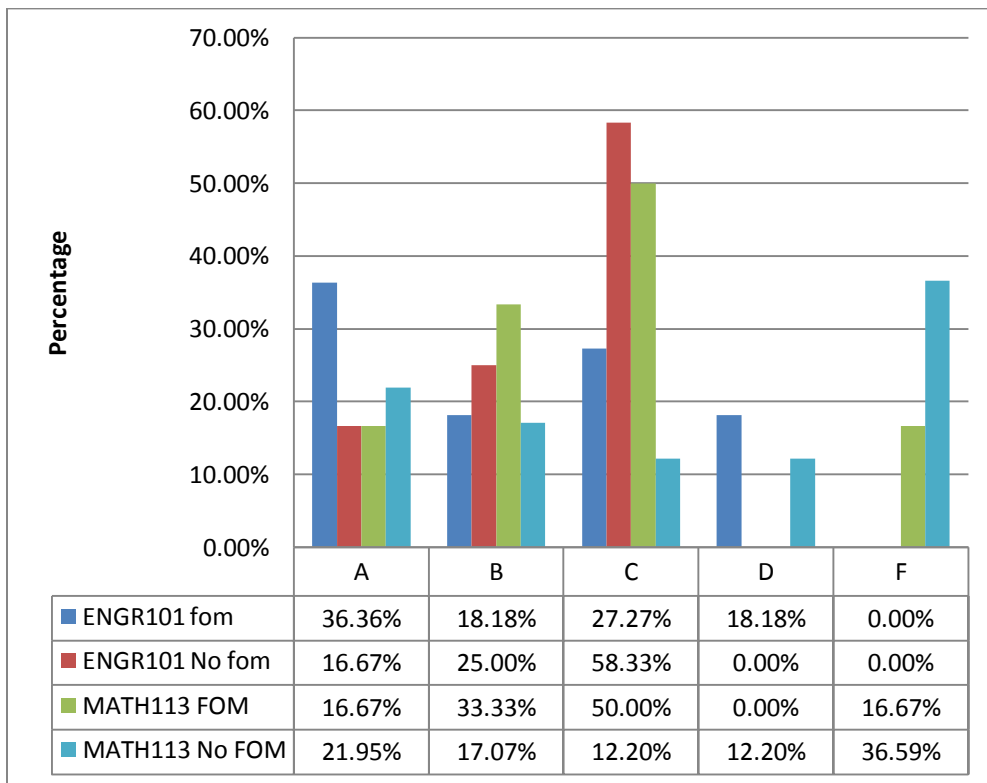


Figure 3 Differentiated instruction engineering course (ENGR101) grade distribution after the first semester and the traditional pre-calculus math course (MATH113) grade distribution

Summary

It has been shown that a focused, holistic approach to redesigning an introductory course sequence can help freshman engineering students build a foundation for ensuing technical subjects. By decreasing the time spent in preparing for Calculus they are able to advance on and enter gate keeper courses that improve their graduation probability. Starting early with a preventative approach and then providing differentiated instruction is shown to be an effective strategy to improve pass rates and improve the overall academic performance of the students. While it is true that a multiplicity of factors contribute to the sub-optimal performance of engineering students in the pre-calculus courses, we contend that we can increase the students desire to understand fundamental mathematical concepts by using these highly interactive lower division math/engineering course sequences in which the faculty will work synergistically to insure that the individualized needs of every student are met.

The School of Engineering at our institution has supported the transition of our earlier mathematics reform efforts from a pilot study to a full offering for every incoming engineering student. This effort could be easily transferred to any interested institution. It requires no special

facilities or personnel only the openness to work across programmatic boundaries in a truly multidisciplinary manner. Furthermore, this approach can be extended to any general education subject area including the language arts, the sciences or even economics.

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