Adapting the National Model for Engineering Mathematics Education to Support Success of Algebra II Students

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Abstract:

In the College of Engineering and Applied Sciences (CEAS), Western Michigan University (WMU), there are 75-100 students who are placed in Algebra II in their first semester annually by either the ACT or SAT math sub-scores, and they form about 20-25% of the first-time first-year student population. Improving the academic success of the Algebra II students and retaining them to the college or to the university is important to enrollment and budget of the university. We have adapted the Wright State University Model of Engineering Education funded by the National Science Foundation for an Introduction to Engineering Analysis course as part of a cohort student success strategy. The details of the engineering mathematics course will be presented, including a week-by-week class schedule and course content. We will present results of student performance in Algebra II and compare to baseline performance and with a comparison group of students taking Algebra II in the same semester. We will also present results of student performance in the follow- up Precalculus and a comparison to performance of comparison groups. Finally, we will present retention rates of the Algebra II students to CEAS and to the university, and a comparison to baseline retention rates. Results show statistically significant improvement in Algebra II performance against the baseline and with a comparison group, and in improvements in performance in Precalculus and in retention rate to institution. Retention rate to CEAS is higher than the baseline, though not statistically significant.

Introduction

The College of Engineering and Applied Sciences (CEAS), Western Michigan University (WMU), has nine EAC-ABET accredited engineering programs (aerospace, chemical, civil, computer, construction, electrical, industrial & entrepreneurial, mechanical, and paper), three ETAC-ABET accredited engineering technology programs (engineering design, engineering management, and manufacturing engineering) and a CAC-ABET accredited computer science program. Our graphics and printing science program is accredited by the Accreditation Council for Collegiate Graphic Communications (ACCGC). In addition, CEAS offers 11 master and six doctoral programs. Fall 2017 enrollment consisted of 2,415 undergraduates, 447 master's students and 158 doctoral students.

The Consortium for Student Retention Data Exchange (CSRDE) of University of Oklahoma

places our university as a "Moderately Selective" institution [1]. About 20-25% of beginning first-year CEAS students are placed into Algebra II during their first semester at our institution base on ACT- or SAT-Math sub-scores. Table 1 on the next page shows the first-semester mathematics enrollment of these CEAS students from 2008 to 2017.

To better inform students of the academic pathways in engineering, engineering technology and applied science programs, the admissions requirement into CEAS was revised in fall 2012. Students who are placed in Algebra II in their first-semester, based on ACT/SAT math sub-scores, are admitted into CEAS Exploratory (CEAS-EXEP), and they must achieve a grade of B or better in Algebra II in no more than two attempts before they can advance their studies in CEAS.

Table 1. First-Semester Mathematics Enrollment for First-Year CEAS Students from 2008 to 2017 Expressed in Percent

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Calculus II or Higher	5.2	7.9	7.5	3.4	4.5	8.0	7.0	13.8	11.7	11.0
Calculus I	39.2	34.3	40.7	38.0	37.2	35.1	35.0	38.1	32.8	38.0
Precalculus	29.8	27.9	25.2	34.0	31.7	33.4	31.9	27.5	24.5	23.3
Algebra II	18.9	22.0	19.1	16.8	24.2	20.8	25.6	19.7	27.9	27.7
Algebra I*	5.9	7.6	6.8	8.4	---	---	---	--	--	--
No Math Data**	1.0	0.3	0.7	0	2.4	2.6	0.4	0.9	3.1	0.0

*Beginning in fall 2012, students with ACT-MATH sub-score of 18 or less (Algebra I and remedial math), are admitted into the university's Exploratory Advising program.
** No Math Data refers to those students who did not take any math course during their first semester, due to Advanced Placement credits (for example).

Since the CEAS-EXEP students form a significant portion of the first-year population, our College implemented an EXEP Cohort program in 2013 to support the success of the Algebra II students. Students in EXEP Cohort are enrolled in the same section of 3-to-4 courses together in fall semester and the same section of 3-to-4 courses in spring semester. Placing first-year students in cohorts or learning communities is recognized by the National Survey of Student Engagement (NSSE) of Indiana University as one of six high-impact practices positively affecting student success and retention [2]. Gabelnick et al. described how cohorts or learning communities promote connection among students, faculty and staff, and with the students' majors [3]. The fall semester courses are the 3 credit-hour Algebra II, a 2 credit-hour First Year Engineering Experience seminar, and a 1 credit hour Introduction to Engineering Analysis recitation. Depending on their intended major, students are also enrolled in a 3 credit-hour Engineering Graphics or General Education course(s) to attain full-time academic status. For the spring semester, students in EXEP Cohort are enrolled in the same section of a 4 credit-your Precalculus, a 3 credit-hour General Chemistry I and a 1 credit-hour Lab, a 3 credit hour Technical Communication, and a CEAS course specific to the student's major or General Education course(s) to attain full-time academic status.

This paper will describe the engineering mathematics course, ENGR 1002, "Introduction to Engineering Analysis," The goal of ENGR 1002 is to improve student learning and success in

Algebra II by applying the concepts and practicing the mathematical operations they learn in Algebra II to solve engineering programs. ENGR 1002 is based on the Wright State University Model for Engineering Mathematics Education [4], which was developed with support from the National Science Foundation. At WSU, it is "a first-year engineering course replacing traditional prerequisites for core sophomore engineering courses" [5], and it has resulted in an increase in retention and graduation in engineering, as well as improvements in graduation grade point average (GPA), student motivation and self-efficacy. The Wright State University Model for Engineering Mathematics Education targets primarily the Calculus I and Precalculus students, while our adaption is focused on Algebra II students.

This paper updates an early paper about ENGR 1002 [6] and it describes the course taught in the fall 2017 semester, with revisions and new results from 2015 to 2017.

Introduction to Engineering Analysis

ENGR 1002 is conducted as a recitation that meets once a week for 150 minutes. The learning objectives of ENGR 1002 are: 1) Demonstrate how Algebra II is applied to solve a variety of engineering problems to connect mathematics to engineering practices in students' first semester; 2) Provide students with additional opportunities to practice algebraic operations and manipulations to gain mastery of Algebra II knowledge and skills; 3) Help students develop the proper method, procedure, habits and mindset in applying mathematics to solve problems in engineering; and 4) Help students develop academic habits crucial to student's future success.

ENGR 1002 is conducted in a hybrid format in which students view video lectures and examples prior to class; take a quiz on the video lecture materials at the start of the class period; and spend the remaining class period working problems under the guidance of the student assistants and the instructor. The instructor does provide just-in-time mini lectures and problem-solving based on the questions students raised at the beginning of class. The video lectures are 10-to-15 minutes long, and they were created using Microsoft Office PowerPoint and TechSmith/Camtasia Relay. Videos of problem solving and engineering examples are 5-to-10 minutes each, and they are created using an Intuit tablet and SmoothDraw, and TechSmith/Camtasia Relay, and model how the instructor approaches the problem in a thinking-out-loud manner. In Fall 2015, Microsoft One Note replaced SmoothDraw in creating the videos of engineering problem-solving. The videos, together with course notes and homework assignments, are posted online on the university *eLearning* platform. They are therefore accessible to students 24/7 and for multiple viewings.

The topics of the course are organized according to how Algebra II is taught in a 14-week course at WMU, with the intention that each week's ENGR 1002 topic is aligned as closely as possible with the topics in Algebra II. The engineering topics covered in ENGR 1002 reflect the academic training of the paper's author, which included a B.S. degree in mechanical engineering, a Ph.D. in metallurgy, and post-doctoral experience in atomic and solid state physics. A week-by-week class schedule of ENGR 1002 used during the fall 2017 semester is shown in Table 2 below, with the algebra and engineering topics covered each week.

Table 2. A Weekly Class Schedule of ENGR 1002 and Engineering Topics

Week	Class Schedule	Engineering Topics	Comments
Week 1	Course Overview and Units	Engineering units and unit Conversion	Address a common student mistake: $(ab)^x \neq ab^x$ or $a^x b$ but = $a^x b^x$
Week 2	Algebraic Expression	Definition and algebraic expressions for Density, Avagadro's Number, Atomic Weight, Number of Moles, Mass Fraction, Volume Fraction and Molar Fraction	Practice algebraic operations and manipulations of the form a = b/c + d/e and a = (b/c)/(d/e)
Week 3	Algebraic Relations	The functional relations relating mass fraction to volume fraction or molar fraction, and vice versa	Learn to derive the algebraic equations relating mass fraction to volume fraction, and vice versa, etc.
Week 4	Review and Hour Exam 1	Review engineering topics in Weeks 1-3	First 90 minutes on review and the last 60 minutes on exam
Week 5	Algebraic Function	Linear coefficient of thermal expansion	Inputs versus outputs; independent variable versus dependable variable; continue to practice algebraic operations and manipulations
Week 6	Algebraic Function	Ohm's law and Hooke's Law; parallel and series arrangement of resistors or mechanical springs	Same as Week 5
Week 7	Review and Hour Exam 2	Review engineering topics in Weeks 5-6	First 90 minutes on review and the last 60 minutes on exam
Week 8	Equation of a Straight Line	Linear interpolation and linear extrapolation; Steam Table	Equation of a straight line; slope and intercept
Week 9	Equation of a Straight Line	Position, speed, and acceleration of a particle	Rate of change; slope and intercept of a straight line
Week 10	Quadratic Equation	Projectiles	Quadratic equation/quadratic formula; interpret solutions with negative values
Week 11	Review and Hour Exam 3	Review engineering topics in Weeks 8-10	First 90 minutes on review and the last 60 minutes exam
Week 12	Exponential and Logarithm Functions	PV^n = constant; present/future value of money	Exponential and logarithm functions; convert an exponential equation into an equation of a straight line
Week 13	Final Exam Review		
Week 14	Final Exam		

Results

The first group of Algebra II students admitted to CEAS-EXEP was fall 2012, and there was not any program specifically created for the 2012 EXEP students. We will use 2012 as the baseline

for this study. In fall 2013, an EXEP Cohort program was created in which the EXEP students of a cohort were enrolled in the same section of Algebra II and a First-Year Experience (ENGR 2100) seminar taught by a CEAS academic advisor. Depending on the EXEP student's intended CEAS major, a third course – for example, Engineering Graphics – was added to the CEAS-EXEP cohort schedule. Beginning in fall 2014, we added ENGR 1002 to the cohort schedule. ENGR 1002 (1 credit hour) together with ENGR 2100 (2 credit hours) add to three (3) credit hours. The addition of ENGR 1002 to the EXEP cohort schedule was made with the recognition that it would not add to a student's tuition, because our institution has a flat tuition rate covering 12-15 credit hours (essentially four or five 3-credit-hour courses a semester). Student performance in Algebra II and in Precalculus in the subsequent semester after taking Algebra II, as well as retention rates to college and to the university are presented below.

1. Student Performance in Algebra II

The performances of the EXEP students in Algebra II from 2012 to 2017 are summarized in Table 3 below, showing the number and the percent of CEAS EXEP students who achieved a grade of B or higher in Algebra II in their first attempt and up-to-two attempts. As shown in Table 3, in the baseline year 2012, 17 out of 62 EXEP students (27.4%) passed Algebra II with grades ≥B in first attempt, and 24 out of 62 (38.7%) in up to 2 attempts. The percent of grades ≥B in Algebra II are all higher for students in EXEP Cohort from 2013 to 2017 than those of the baseline (2012). We performed Chi Square test to test the hypothesis that the higher percent of EXEP students with grades ≥B in Algebra II in 2013 to 2017 is correlated with the EXEP Cohort program.

Table 3. Performance of EXEP Students in Algebra II

Year	Total # Students	# ≥B, 1st Attempt	# ≥B, 2 Attempts
2012 (baseline)	62	17 (27.4%)	24 (38.7%)
2013 Cohort	79	29 (36.7%)	41 (51.9%)
2014 Cohort	90	45 (50.0%)	55 (61.1%)
2015 Cohort**	80	29 (36.3%)	46 (57.5%)
2016 Cohort	73	47 (64.4%)	50 (68.5%)
2017 Cohort	98	39 (39.8%)	

** Instructor was hospitalized in mid-October; teaching assistants finished up the course

Using $\alpha \leq 0.05$ and a degree of freedom of 4 (5 – 1; 5 cohorts from 2013 to 2017), we validate the hypothesis that the higher percent of EXEP students who have grades ≥B in Algebra II in their first attempt is correlated with the EXEP Cohort program. Similarly, using $\alpha \leq 0.05$ and a degree of freedom of 3 (there is no data yet for the 2017 EXEP Cohort for up-to 2 attempts in Algebra II), we conclude the hypothesis is also correlated with the EXEP Cohort program for up to 2 attempts of Algebra II.

We next compared the CEAS EXEP students' performance in Algebra II with a group consisting of all students who are enrolled in Algebra II in the same semester as the CEAS EXEP students. The results are summarized in Table 4. We performed Chi Square tests to test the hypothesis that the greater percent of grades ≥B in Algebra II observed for the CEAS EXEP students than the comparison groups is correlated with the EXEP Cohort program.

Table 4. Performance in Algebra II of CEAS-EXEP and Comparison Group

Semester	Total # CEAS-EXEP Students	# ≥B 1st Attempt	Total # Comparison	# ≥B
2012 (baseline)	62	17 (27.4%)	389	77 (19.8%)
2013 Cohort	79	29 (36.7%)	357	70 (19.6%)
2014 Cohort	90	45 (50.0%)	337	64 (19.0%)
2015 Cohort**	80	29 (36.3%)	335	77 (23.0%)
2016 Cohort	73	47 (64.4%)	282	62 (22.0%)
2017 Cohort	98	39 (39.8%)	260	93 (35.8%)

** Instructor was hospitalized in mid-October; teaching assistants finished up the course

There is no statistically significant difference between the EXEP students in the baseline year with the comparison group. Using $\alpha \leq 0.05$ and a degree of freedom of 4 (5 – 1; 5 cohorts from 2013 to 2017), we validate the hypothesis that the higher percent of CEAS EXEP students with grades ≥B in Algebra II than the comparison groups is correlated with the Cohort program.

2. Performance in Precalculus in the Subsequent Semester Following Algebra II

The performance of the EXEP students in Precalculus in the subsequent semester following Algebra II are summarized in Table 5, which gives the number and percent of the EXEP students with grade ≥C in Precalculus.

Table 5. Performance of CEAS EXEP Students in Precalculus in Semester Immediately Following Algebra II

Year	Total # of EXEP students	Total # of EXEP Students in Precalculus in Semester Immediately Following Algebra II with Grades ≥B	#/ (%) of EXEP Students with Grade ≥C in Precalculus
2012 (baseline)	62	17	17 (100%)
2013 Cohort	79	27	22 (81.5%)
2014 Cohort	90	45	42 (93.3%)
2015 Cohort	82	26	23 (88.5%)
2016 Cohort	73	44	37 (84.1%)

As shown in Table 5, 17 out of 17 EXEP students (100%) in the baseline year (2012) passed Precalculus with grades ≥C. Although in subsequent years (2013 to 2016), the percent of students with grades ≥C in Precalculus is less than 100%, we do not think the EXEP Cohort is the cause and therefore make no further analysis.

We compare the performance of the EXEP students with a comparison group made up of all other students taking Precalculus in the same semester as the EXEP students, and the results are summarized in Table 6.

Table 6. Performance in Pre-Calculus (the Following Spring Semester) of CEAS-EXEP and Comparison Group

Semester	Total # CEAS-EXEP in Pre-Calculus	# Grades ≥C	Total # Comparison in Pre-Calculus	Grades # ≥C
2013 Cohort	29	22 (75.9%)	240	155 (64.6%)
2014 Cohort	45	42 (93.3%)	290	183 (63.1%)
2015 Cohort	26	23 (88.5%)	268	169 (63.1%)
2016 Cohort	44	37 (84.1%)	108	49 (45.4%)

Table 6 shows there are higher percent of EXEP students than the comparison groups to have grades ≥C in Precalculus. We perform Chi Square test to test the hypothesis that the higher percent is correlated to the EXEP Cohort program. Using $\alpha \leq 0.05$ and a degree of freedom of 3 (4 – 1; 4 cohorts from 2013 to 2016), we validate the hypothesis that the higher percent of EXEP students with grades ≥C in Precalculus is correlated with the EXEP Cohort program.

3. Retention to CEAS and to WMU

We next analyze 1st-to-2nd year retention to CEAS and to the institution of the EXEP students. In the baseline year (2012), the retention rate to CEAS is 40.3% and the retention rate to WMU is 64.5%. The number and percent of the EXEP students returning to CEAS and to WMU are summarized in Table 7 below.

Table 7. Retention to CEAS and WMU of the CEAS EXEP Students

Year	Total # EXEP Students	2nd-Year Retention to CEAS	2nd-Year Retention to WMU
2012 (baseline)	62	25 (40.3%)	40 (64.5%)
2013 Cohort	79	39 (49.4%)	67 (84.8%)
2014 Cohort	90	51 (56.6%)	83 (92.2%)
2015 Cohort**	80	42 (52.5%)	57 (71.3%)
2016 Cohort	73	37 (50.7%)	52 (71.2%)

**Instructor was hospitalized in mid-October; Teaching Assistants finished the course

Table 7 shows that the retention rates to CEAS and to WMU for the EXEP students in the Cohort program in 2013 to 2017 are higher than the baseline (2012) retention rates. We perform Chi Square test to test the hypothesis that the higher retention rates are corrected to the EXEP Cohort program. Using $\alpha \leq 0.05$ and a degree of freedom of 3 (4 – 1; 4 cohorts from 2013 to 2016), we validate the hypothesis that the higher retention rate to WMU is correlated to the EXEP Cohort program. The higher retention rates to CEAS of the EXEP students in the Cohort program are higher than the baseline EXEP students without Cohort, but not statistically significant.

Conclusion and Future Work

The implementation of the EXEP Cohort program in 2013 and the subsequent inclusion of ENGR 1002, Introduction to Engineering Analysis, as part of the cohort course schedule in 2014 are correlated with a higher percent of EXEP students over the baseline in achieving grades ≥B in Algebra II in first attempt and no-more-than 2 attempts, and a higher percent

than comparison groups of students taking Algebra II in the same semester as the EXEP students. The EXEP Cohort program is also correlated with a higher percent of EXEP students with grades ≥C in Precalculus than comparison groups of other students enrolled in the same semester as the EXEP students, as well as a higher retention rate of the EXEP students to the institution than the baseline. Retention rates to CEAS of the EXEP students in the Cohort program are higher than the baseline without the Cohort program, but not statistically significant.

Future work will include investigating the impact of the engineering mathematics course, ENGR 1002, on performance in Algebra II and Precalulus, and retention to CEAS and to the institution. This will be accomplished by comparing the results of 2014 and later years to the 2013 Cohort, before ENGR 1002 was added to the cohort class schedule.

Reference

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