AC 2011-176: IMPACT OF COLLABORATIVE PROBLEM-SOLVING WORKSHOPS IN ENGINEERING CALCULUS COURSE ON APPLIED MATHEMATICAL

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Impact of Collaborative Problem-solving Workshops in Engineering Calculus Course on Applied Mathematical Problem-solving Skills and Self-efficacy Perceptions

Abstract

This project stems from a collaborative effort by engineering and mathematics faculty at a research university to enhance engineering students' abilities to transfer and apply mathematics to solve problems in engineering contexts. A recent curriculum innovation resulting from these efforts involves the integration of collaborative, applied, problem-solving workshops into the first-semester engineering mathematics course. In the first year of the assessment project, the project team developed two instruments - one to gauge students' abilities in using mathematics in engineering contexts, the Mathematics Applications Inventory (MAI); and the other to gauge students' self-efficacy perceptions related to studying engineering and to learning and applying mathematics, the Engineering and Mathematics Perceptions Survey (EMPS). In this second year of the project we will use the instruments to detect effects of the workshop innovation. The project is funded by the National Science Foundation, Directorate of Education and Human Resources, Course, Curriculum, and Laboratory Improvement (CCLI) Program, Grant # DUE-0837757.

This paper reports the results of the full administration of both instruments in Fall 2010 to all first-year engineering students at our institution (approximately 820). Slightly less than half enroll in the first calculus course in the engineering mathematics sequence, which covers single variable calculus and includes the collaborative problem-solving workshop innovation. The other first-year students have obtained advanced standing through prior coursework or credit on Advanced Placement exams, and the majority of these enroll in the second course in the sequence, which covers multivariable calculus and does not include the workshop component. All students in each course will complete the MAI as a paper-and-pencil exam during class time at the outset of the semester and again at the end of the semester. All students will also be asked to complete the online EMPS survey at both pre- and post-semester.

This paper includes analyses of the resulting data, including associations between EMPS responses and MAI performance, patterns in students' responses to the problems on the MAI, common areas of difficulty related to the application of specific mathematical topics, and patterns of responses and performance by other background and status variables such as gender, race, SAT scores, and level of mathematics preparation. Comparisons of responses pre- and post-semester, as well as comparisons across courses, will help determine impacts of the workshop innovation.

We expect that students' experiences in the workshops will improve their general abilities to apply the mathematics they have learned to engineering-related problems, and will have positive effects on their self-efficacy perceptions related to succeeding in the engineering curriculum. Our findings will help determine whether positive impacts on student skill and self-efficacy are indeed occurring in ways we are able to detect with the use of these instruments.

Introduction

The aim of this project is to assess the effects of integrating engineering applications into core mathematics courses for engineers. We expect this innovation will 1) enhance students' *skill* applying mathematics to solve problems involving physical quantities and relationships; and 2) enhance students' *confidence* about their ability to use mathematics to solve problems and their ability to succeed in the engineering curriculum**.** In earlier papers we have explained the origins of the project, described the process of instrument development, and reported on preliminary findings from pilot data collection efforts during the 2009-2010 academic year (Schneider and Terrell, 2010; Terrell, Terrell, and Schneider, 2010). In this paper we will summarize the project background, goals, and instrument development process, and report on findings from our full data collection effort in Fall 2010.

Local Background

Entering engineering students at our university have median SAT Math scores of approximately 750 and Verbal scores of approximately 685. Credit for the equivalent of first semester calculus is expected at entrance (i.e., the equivalent of a 4 or 5 on the AB Advanced placement examination). The first mathematics course for half of the entering class is the equivalent of second semester calculus, for the other half it is multivariable/vector calculus or higher. By all the usual measures we have a very able and motivated group of students. Yet engineering faculty at our institution consistently report that students in introductory engineering courses have difficulty using even elementary mathematics to represent quantities and relationships between them. This inability to use the mathematics that they have apparently learned has been all the more perplexing since the core engineering mathematics courses are taught jointly by mathematicians and faculty in engineering.

We believe this mismatch between students' apparent background and their depth of understanding and ability to apply concepts to new problem situations is by no means unique to our institution. Many schools face it, and some new understanding of why this is happening, and some evaluation of whether a particular intervention improves things, will have wide implications nationally.

In 2006 the Dean of the Engineering College at our institution formed a Curriculum Task Force. The task force was charged with developing recommendations for changes in the college's core curriculum that would reflect and implement the Undergraduate Studies Objectives of the college:

- Enhance the undergraduate educational environment and experience.
- Enhance the engineering undergraduate curriculum and implement procedures for assessment and change.
- Become a leader in the education of women and underrepresented minority engineers.

As the result of the task force's work, the faculty of the College of Engineering voted in 2006 to adopt curriculum reform efforts that had as a primary objective to link first year core courses in mathematics and physical sciences with engineering applications. In Spring 2007 the Department of Mathematics curriculum committee, in cooperation with faculty and administrators from Engineering, approved a plan to infuse first semester engineering mathematics with collaborative, problem-solving workshops. The first set of materials was written by teams of engineers from across the college and by pure and applied mathematicians. Engineering faculty teaching the 200-level engineering courses in which basic calculus is routinely applied wrote the original problems, which were subsequently reviewed and revised by a liaison committee of mathematics and engineering faculty.

Beginning in Fall 2007, applied problem-solving was integrated into the first course in the required engineering math sequence by transforming one of the two weekly teaching assistant-led recitation sections into a collaborative problem-solving workshop. All sections (typically sixteen) of the course receive the workshop innovation. As such, all students enrolled in the course (approximately 350-400 each fall semester) participate in the workshops. The workshops are facilitated by the section teaching assistants along with upper-class undergraduate engineering students serving as course assistants. The teaching assistants and course assistants receive training on facilitating active, collaborative problem-solving. The training is developed and led by engineering faculty and staff, drawing on other successful collaborative learning efforts in the college.

In the workshops students are instructed to work in groups on the applied problems. Teaching assistants and course assistants facilitate the group work and provide guidance where necessary. Students are encouraged to discuss and grapple with the problems together with their group members and to help each other to collectively reach a solution.

Goals within the Broader Context of Engineering Education

The challenges of assessing learning outcomes in education in general are significant, if not daunting. Over the past decade engineering educators have developed a framework for defining the notion of "learning outcomes" and have established a list of eleven learning outcomes essential for ABET accreditation. The first of those outcomes, which addresses the basic scientific knowledge needed by engineers, includes: *An ability to apply knowledge of mathematics, science and engineering.* The emphasis of this outcome is on:

> *Formulation and solution of mathematical models describing the behavior and performance of physical, chemical, and biological systems and processes; and use of basic scientific and engineering principles to analyze the performance of processes and systems.* (Besterfield-Sacre et al., 2000)

Central to the framework is the understanding that true learning cannot be measured without observable behavior. Each learning outcome must reflect the integration of the cognitive and the behavioral – the knowing and the doing.

Further, research has shown that what students think about their learning experiences (attitudinal outcomes) is also a critical component in understanding student performance, especially in the first year (Besterfield-Sacre, Atman, and Shuman, 1997; Besterfield-Sacre, Moreno, Shuman, Atman, 1999; Hutchison-Green, Follman and Bodner, 2008; Hutchison et al., 2006). Our goal is to develop two instruments to assess the student learning and attitudinal outcomes resulting from innovations in content and teaching methodology in our first year calculus courses for engineers. The instruments will be designed to gather data on 1) students' *abilities* to apply mathematics to represent physical quantities and relationships, both before and after their participation in the problem-solving workshops; and 2) students' *confidence* in their abilities to use mathematics to solve problems and to succeed in the engineering curriculum, both before and after their participation in the problem-solving workshops.

The need for research on, and development of, assessment instruments and metrics to inform engineering education practice has been well documented. In 2006, the Engineering Education Research Colloquies (EERC) presented five research areas to serve as the foundation for the new discipline of Engineering Education (Steering Committee of the National Engineering Education Research Colloquies, 2006a, 2006b). Our evaluation of this curricular change will contribute to three of those areas: Engineering Learning Mechanisms, Engineering Learning Systems, and Engineering Assessment.

Engineering Learning Mechanisms: We are eager to gain insight into how engineering students develop problem solving competencies in the context of mathematical modeling. The questions we will investigate related to this area are:

1) How skilled are students at applying mathematics to solve problems involving physical quantities and relationships at the point of college entrance?
2) Does regular participation in problem solving engineering applications workshops enhance students' skill at applying mathematics to solve problems involving physical quantities and relationships?

Engineering Learning Systems: We are eager to learn about the effect that instructional culture has on student learning, retention and transfer of knowledge within the engineering curriculum. The third question we are interested in exploring is:

3) Does regular participation in collaborative engineering applications workshops enhance students' confidence about their ability to use mathematics to solve problems?
4) Does regular participation in collaborative engineering applications workshops enhance students' confidence about their ability to succeed in the engineering curriculum?

Engineering Assessment: The main work of this project will be to produce two assessment instruments to measure the effects of our curriculum innovation on engineering students' abilities and confidence in applying mathematics to physical phenomena and problem-solving. Our aim is to develop instruments that can be widely used to inform approaches to mathematical instruction for engineering students and to ultimately improve the effectiveness of engineering educational practice.

Related studies have demonstrated the benefits of integrating math, science, and engineering instruction in the early years of the engineering curriculum (Carr, 2003; Froyd and Ohland, 2005; National Academy of Engineering, 2005; Olds and Miller, 2004), of providing active, collaborative learning environments in engineering courses (Felder, Felder and Dietz, 1998; Johnson, Johnson and Smith, 1998a, 1998b; Prince, 2004; Springer, Stanne and Donovan, 1999; Terenzini et al., 2001), of attending to student attitudes and beliefs regarding their own ability to succeed in engineering (Besterfield-Sacre, Atman, and Shuman, 1997; Besterfield-Sacre, Moreno, Shuman, Atman, 1999; Hutchison-Green, Follman and Bodner, 2008; Hutchison et al., 2006; McKenna and Hirsch, 2005; Ponton et al., 2001), and of improving mathematics instruction by attending to students' understanding of central concepts (Bingolbali, Monaghan and Roper, 2007; Epstein, 1997; Ferrini-Mundy and Graham, 1991; Schoenfeld, 1997). We plan to add to this research base on the effects of curriculum innovation on student learning outcomes, and to provide tools to improve our collective ability to specify, detect, and understand those outcomes.

Instrument Development

Mathematics Applications Inventory (MAI)

The Mathematics Applications Inventory, MAI, is intended to measure the level at which first year undergraduate engineering students can apply basic mathematical tools for expressing rate of change (variable and constant-ratios and derivatives) and accumulation (finite sums of products or infinite sums of products-definite integrals) in physical contexts. The key mathematical concepts for the MAI were identified through a modified "Delphi study" of elementary mathematics applications in engineering courses involving faculty from across all engineering and physical science disciplines at Cornell. Based on that study, and in consultation with experts in mathematical diagnostic testing and educational assessment instrument validation, test items were developed.

The test includes five questions with a total of 11 sub-questions. Student responses to the initial set of open ended questions in Fall 2009 were used to refine the questions and to develop a set of distracters for the multiple choice version of the instrument. The questions are intended to be accessible to students who have completed the equivalent of first semester single variable differential and integral calculus, equivalent to an AB advanced placement course, in high school. The questions focus primarily on applications in which the independent variable is not time. This was a necessary consequence of avoiding applications which were too similar to Advanced Placement test problems. The MAI questions are designed to be more conceptual and less computational, although some questions do require some elementary computations. The mathematical concepts represented on the MAI from pre-calculus are average of numbers, average rate of change, fractional change, reasoning from and about graphs/graphical displays, asymptotic behavior, and signed numbers (arithmetic with positive and negative numbers). The mathematical concepts from introductory calculus include the derivative, the definite integral, and the fundamental theorem of calculus. MAI items were categorized into a short taxonomy based on the mathematical content area(s) represented and the cognitive process (knowing, applying, or reasoning) required to solve the item.

In addition to analyzing students' open-ended responses to the MAI test items, researchers also conducted in-depth interviews with a sample of fourteen students immediately following the Fall 2009 pretest. Students were shown their test responses and asked four questions about their response to each item. The questions probed students' confidence in their answers, perceived familiarity with the type of question, cognitive process engaged in to solve the problem, and alternative ideas they had about solving the problem. Interview responses yielded important insights into the cognitive processes students' used in answering the questions and further informed the development of response options for the revision of the MAI into a multiple choice inventory.

A more detailed description of the MAI development process and item characterization can be found in the previous paper dedicated to the topic, *Assessing Engineering Students' Ability to Use the Mathematics They Have Learned* (Terrell, Terrell, and Schneider, 2010).

Engineering and Mathematics Perceptions Survey (EMPS)

The Engineering and Mathematics Perceptions Survey, EMPS, is intended to measure the confidence of first year undergraduate engineering students in their abilities to do well in mathematics courses, to apply the mathematics they have learned to solve word problems, and to succeed in the engineering curriculum. It also is intended to measure students' sense of positive connection to other engineering and university students, and the value students place on learning mathematics. The EMPS is a 28-item online survey adapted from the Longitudinal Assessment of Engineering Self-Efficacy (LAESE) instrument developed as part of the NSF-funded Assessing Women in Engineering (AWE) project (Assessing Women in Engineering (AWE) Project, 2007).

The LAESE was designed to measure undergraduate students' self-efficacy related to succeeding in the engineering curriculum, as well as feelings of inclusion in the academic environment, ability to cope with setbacks or challenges related to the college environment, and expectations about engineering career success and math outcomes. The original use of the instrument was focused on self-efficacy among undergraduate women engineering students, and specifically on the relationship of self-efficacy and the other related constructs to students' persistence in engineering (Marra et al., 2004). Following its development in 2003, the LAESE was used as the primary instrument for a longitudinal multi-institution study of self-efficacy among male and female engineering students at five institutions across the United States. Validity and reliability were analyzed for all items and subscales and found to be acceptable (Marra and Bogue, 2006; Marra et al., 2007).

For our purposes, we retained four of the six subscales included in the LAESE instrument: engineering self-efficacy I (five items), engineering self-efficacy II (six items), feelings of inclusion (four items), and math outcomes expectations (three items). We created our own subscale intended to measure math applications self-efficacy (three items). Thus, the final EMPS instrument includes subscales to measure: 1) Self-efficacy perceptions related to succeeding and earning high grades in the engineering curriculum (*Engineering self-efficacy I)*; 2) Self-efficacy perceptions related to completing an engineering degree (*Engineering self-efficacy II*); 3) *Feeling of inclusion* with other students in courses and campus activities; 4) Expectation of positive outcomes related to persistence and success in mathematics courses (*Math outcomes expectations);* and 5) Self-efficacy perceptions related to applying mathematics to solve problems (*Math applications self-efficacy*). We also retained LAESE items asking students their perceptions about the amount of work required to get the grades they want in college versus the amount of work required to get the grades they wanted in high school, and about their confidence that they will complete an engineering degree. For the posttest survey (administered in the final week of the semester), we added a question asking students to estimate the final grade they expect to receive in their first-semester math course, and to rate how confident they are about their estimate.

Data Collection

The Mathematics Applications Inventory (MAI) and the Engineering and Mathematics Perceptions Survey (EMPS) were piloted in Fall 2009 (N=79) and Spring 2010 (N=354). Findings from these pilot administrations informed minor instrument revisions and established validity and reliability. Preliminary findings from these data were reported in earlier publications (Schneider and Terrell, 2010; Terrell, Terrell, and Schneider, 2010).

The MAI and EMPS were administered in Fall 2010 to all students in the first-semester engineering mathematics course, *Calculus for Engineers*. Slightly less than half of all incoming engineering students enroll in this course (N=379). Students in this course participate in the collaborative, applied problem-solving workshop innovation throughout the semester. As a control group, we also administered the instruments to all students in the second course in the engineering mathematics sequence, *Multivariable Calculus for Engineers*. Incoming engineering students who already have credit for the first calculus course, through AP or advanced course credit, enroll in this course in the first semester of their freshman year (N=441). *Multivariable Calculus for Engineers* does not have a collaborative, applied problem-solving component.

For both courses, the MAI pretest was administered as a pencil-and-paper in-class test during the first week of the semester. An invitation to complete the online EMPS pretest was also e-mailed to all students in both courses in the first week of the semester. The nature of the research project was explained verbally, by teaching assistants in the course sections, and was also explained in writing in the invitation e-mail and the online consent form. Students were encouraged to participate, but also informed that their participation was voluntary. During the second to last week of the semester, after the last workshop had taken place in the *Calculus for Engineers* course, all students in both courses were again asked to respond to the online EMPS posttest and to complete the in-class MAI posttest in the same fashion.

In order to test the comparability of the open-ended and multiple-choice versions of the MAI, the open-ended version was administered to a subset of students in each course, at both pretest and posttest, while the majority completed the multiple-choice version at both times. Sections of the course receiving the open-ended version were matched by section time and by teaching assistant instructor with other sections receiving the multiple-choice version. This will allow a comparison of student performance while controlling for instructor effects and section time effects.

Of the 379 engineering students enrolled in *Calculus for Engineers,* 338 completed the pretest MAI, with 237 completing the multiple-choice version and 106 completing the open-ended version. Meanwhile 180 *Calculus for Engineers* students completed the pretest EMPS. Of the 441 engineering students enrolled in *Multivariable Calculus for Engineers,* 422 completed the pretest MAI, with 322 completing the multiple-choice version and 102 completing the open-ended version. Meanwhile 203 *Multivariable Calculus for Engineers* students completed the pretest EMPS.

Response rates were considerably lower at posttest. Consistent with a decrease in recitation section attendance at the end of the term, many students were absent on the day the MAI posttest was administered in section. Also, fewer students opted to complete the online instrument at posttest than at pretest. Thus, 246 *Calculus for Engineers* students completed the posttest MAI, with 165 completing the multiple-choice version and 81 completing the open-ended version. Meanwhile 82 *Calculus for Engineers* students completed the posttest EMPS. For the *Multivariable Calculus for Engineers* course, 293 completed the posttest MAI, with 233 completing the multiple-choice version and 60 completing the open-ended version. Meanwhile 91 *Multivariable Calculus for Engineers* students completed the posttest EMPS.

Data Analysis

Data analysis methods include observation of score distributions and gains from pretest to posttest by course for MAI scores and self-efficacy subscale scores; bivariate regression analyses to determine the estimated effect of each key independent variable, considered in isolation, on MAI performance at both pretest and posttest; and a General Linear Model regression analysis to test for a course effect on MAI gain while controlling for the other significant variables identified.

As described above, we are utilizing students in the second course in the engineering mathematics sequence, *Multivariable Calculus for Engineers,* as a control group. Students in this course do not receive the applied, problem-solving workshop treatment. However, this is an imperfect control because the students who immediately enroll in this second course during their first semester in the college either have a more advanced mathematics background than those enrolling in the first course in the sequence, *Calculus for Engineers,* or have greater confidence in the level of proficiency they have attained through their advanced math background and thus choose to use their pre-college course or AP credit to forego taking the *Calculus for Engineers* course and skip ahead to the second course. Thus, the groups are non-equivalent at the outset, either due to differences in their mathematics preparation or proficiency level, or due to selection bias for those whom enrollment in the second course was an option (due to AP credit, pre-college course credit, or math placement test scores) and thus had the choice of enrolling in the first course anyway or immediately enrolling in the second course.

In order to reduce the influence of this nonequivalence, the differences by course in MAI gain scores were tested using propensity-score-based-stratification. Background variables were used in a binary logistic regression model to predict the probability for each student of being enrolled in the second course vs. the first course. This process produced five balanced strata including students enrolled in either course, but similar to each other in terms of the college preparatory test scores and demographic statuses that influence the likelihood of being enrolled in the second course. Specifically, the variables included in the process of assigning students to the appropriate quintile included: SAT scores on math, verbal, math1, math2, physics, and chemistry tests; ACT scores on math and engineering tests; racial or ethnic status; and gender. Due to a high percentage of missing values in high school background variables, multiple imputation technique was used to produce ten similar data sets, each containing the observed and the imputed values. Balance of continuous variables within propensity score quintiles was assessed using a Kolmogorov-Smirnov test for the equality of distributions, and Fisher's exact test was used to assess balance on gender and ethnicity.

In this way, quintiles one through five were defined, with quintile five including students with test scores and status profiles most consistent with enrollment in the second course, and those in quintile one including students with test scores and status profiles least consistent with enrollment in the second course. Comparisons by course enrollment within each quintile allow course effects to be tested among groups of matched students, thus compensating for the nonequivalence and selection bias that would be present in a direct comparison of the two courses.

General analyses were performed using SAS 9.2 (Cary, NC: SAS Institute Inc.), and R statistical software version 2.12.1 (The R Foundation for Statistical Computing, 2010). Multiple imputations were done using the "Amelia" package (Honaker et. al., 2010) for R, while the "PSAgraphics" package (Helmreich & Pruzek, 2009) for R was used to assess covariate balance after propensity score stratification.

Results

Below we report demographic frequencies to demonstrate the characteristics of our respondent groups; score distributions by course for our central variables of interest; results of bivariate regression analyses estimating the effect of each key independent variable, considered in isolation, on MAI performance; and results of a General Linear Model regression analysis to test for a course effect on MAI gain while controlling for the other significant variables identified.

Tables 1 reports demographic frequencies, by gender and by racial/ethnic status, with respondents grouped by course enrollment. These frequencies provide a snapshot of the demographic composition of the initial respondent group completing the MAI at pretest. As described above, only a subset of these students responded to the MAI at posttest, and smaller subsets responded to the online EMPS at pretest and at posttest. Thus, it is important to note that total numbers, and demographic composition, of respondents will vary depending on which set of data is being utilized.

Table 1: Demographic Frequencies by Course for Students Completing MAI Pretest

	Math 1910 Respondents		**Math 1920 Respondents**	
	Frequency	Percent	Frequency	Percent
Male	193	57%	282	67%
Female	145	43%	140	33%
Total	338	100%	422	100%
White	177	52.4%	163	38.6%
Asian	46	13.6%	119	28.2%
International	24	7.1%	41	9.7%
Hispanic	29	8.6%	27	6.4%
Black	14	4.1%	6	1.4%
Native American	1	.3%	3	.7%
Multi-URM	9	2.7%	8	1.9%
Multicultural	7	2.1%	11	2.6%
Other	31	9.2%	44	10.4%
Total	338	100%	422	100%

In the race and ethnicity categories reported above, "International" refers to non-US citizens of any race or ethnicity. The other categories are American citizens. Since Black, Hispanic, and Native American students are underrepresented in undergraduate engineering enrollments in the United States, these categories are grouped together in the analyses as underrepresented minorities (URM). "Multi-URM" refers to students with multiple racial or ethnic identities, with at least one of those being in a group classified as URM. These also are grouped in the URM category for the analyses. "Multicultural" refers to students with multiple racial or ethnic identities, none of which are classified as URM; and "Other" refers to students who decline to report their race or ethnicity, or who indicate their identity as other than the given categories.

Table 2 illustrates the distribution of scores, by course, on the Math Applications Inventory (MAI) multiple-choice version (MC) or open-ended version (O-E), the Self-Efficacy scale for Success in the Engineering Curriculum (EngSEsucceed), the Self-Efficacy scale for Completion of the Engineering Curriculum (EngSEcomplete), and for the Math Applications Self-Efficacy scale (MathAppsSE). Mean scores are reported for each group at pretest and at posttest; as well as calculated Gain scores, showing average gains on each measure from pretest to posttest. Distributions for final course grade for each course are also reported.

Course numbers are used to refer to the two difference courses. 1910 is the first course in the engineering mathematics sequence, *Calculus for Engineers.* 1920 is the second course in the engineering mathematics sequence, *Multivariable Calculus for Engineers.*

Table 2: Scores Distributions by Course

		N	Min	Max	Mean	Stddev
1910 MAI score	**Pre MC**	237	1	10	5.42	1.649
	Post MC	165	2	10	5.98	1.887
	Pre OE	106	0	10	2.81	1.674
	Post OE	81	0	9	3.89	1.969
1920 MAI score	**Pre MC**	322	1	11	6.43	1.965
	Post MC	233	1	11	7.06	2.028
	Pre OE	102	0	9	4.30	2.142
	Post OE	60	0	10	4.98	2.303
1910 MAI Gain	**MC**	165	-5	5	.56	1.995
	OE	79	-3	7	1.15	2.094
1920 MAI Gain	**MC**	233	-7	6	.55	2.061
	OE	60	-3	5	.75	2.039
1910 EngSE succeed	**Pre**	180	2.80	7.00	5.4444	.73524
	Post	82	1.80	6.80	5.1878	.91889
1920 EngSE succeed	**Pre**	203	2.40	7.00	5.5879	.92953
	Post	90	2.20	7.00	5.2322	1.23598
1910 EngSE succeed Gain		65	-2.40	1.40	-.2331	.85249
1920 EngSE succeed Gain		59	-2.80	1.20	-.3212	.78418
1910 EngSE complete	**Pre**	175	3.67	7.00	5.8517	.65802
	Post	80	1.00	7.00	5.5708	.98361
1920 EngSE complete	**Pre**	198	1.00	7.00	5.9157	.98553
	Post	87	1.00	7.00	5.7406	1.00355
1910 EngSE complete Gain		64	-5.17	2.17	-.2708	.99003
1920 EngSE complete Gain		56	-6.00	1.00	-.4280	1.02759
1910 MathAppsSE	**Pre**	175	3.67	7.00	5.8438	.74838
	Post	80	1.00	7.00	5.7021	1.08263
1920 MathAppsSE	**Pre**	198	1.00	7.00	5.8956	1.01166
	Post	87	1.33	7.00	5.8429	1.02279
1910 MathAppsSE Gain		64	-5.67	2.33	-.0964	1.04730
1920 MathAppsSE Gain		56	-5.67	1.67	-.2202	1.00157
1910 Final Grade		331	.00	4.30	2.7798	.87952
1920 Final Grade		408	.00	4.30	2.7971	.89944

From the above, we observe similar patterns of gains on the MAI across the two courses, with the 1920 students achieving higher overall pretest and posttest scores, but with the 1910 students obtaining greater average gain on the open-ended MAI version. For the self-efficacy measures, students in 1920 tend to begin the semester somewhat more confident than their peers enrolled in 1910 in their ability to apply mathematics and to complete, and succeed in (or earn A’s or B’s), the engineering curriculum. However, while students from both courses experience losses, on average, over the semester in these self-efficacy perceptions, the students in 1920 tend to experience greater losses on average in self-efficacy scores.

Results of the bivariate regression analyses, reported in Tables 3, 4, and 5 below, further explore the influences on MAI performance of the central variables in the model. We report the estimated power of gender; race/ethnicity; MAI form; mathematics course enrollment; self-efficacy in relation to succeeding, or performing very well, in the engineering curriculum; self-efficacy in relation to completing the engineering curriculum; and self-efficacy in relation to applying mathematics to solve word problems, for predicting MAI scores. In these analyses we are not reporting the relationships between pre-college test scores and MAI performance. The positive associations between SAT, AP, and ACT test scores and MAI performance have been reported and discussed in our earlier work (Schneider and Terrell, 2010; Terrell, Terrell, and Schneider, 2010). The influences of these indicators of pre-college proficiency are accounted for in the full regression model by virtue of their inclusion in the creation of the matched strata.

Table 3: Pretest Mathematics Applications Inventory Score Predictors

Effect	**Category**	**Estimate**	**StdError**	**DF**	**t Value**	**Pr>[t]**	**N**	**Pr>F***
Gender	InterceptMale	5.5375	0.1012	765	54.73	<.0001	767	0.0012
	Female	-0.5375	0.1654	765	-3.25	0.0012	767	
Race/Ethnicity	InterceptWhite	5.3557	0.1196	762	44.78	<.0001	767	0.0057
	Asian	-0.08460	0.2094	762	-0.40	0.6864	767	
	Internat'l	0.6294	0.2959	762	2.13	0.0337	767	
	Other	0.2142	0.2590	762	0.83	0.4084	767	
	URM	-0.6414	0.2537	762	-2.53	0.0117	767	
MAIForm	InterceptOE	3.5433	0.1349	765	26.28	<.0001	767	<.0001
	MC	2.4603	0.1580	765	15.58	<.0001	767	
Course	Intercept1920	5.9198	0.1037	765	57.08	<.0001	767	<.0001
	1910	-1.3047	0.1551	765	-8.41	<.0001	767	
Intercept		1.7262	0.7551	380	2.29	0.0228	382	
EngSEsuccPre		0.6769	0.1352	380	5.01	<.0001	382	
Intercept		3.3052	0.8299	370	3.98	<.0001	372	
EngSEcompPre		0.3670	0.1396	370	2.63	0.0089	372	
Intercept		3.3919	0.7828	370	4.33	<.0001	372	
MathAppsSEpre		0.3531	0.1318	370	2.68	0.0077	372	

*Indicates overall significance for categorical variables.

Table 4: Posttest Mathematics Applications Inventory Score Predictors

Effect	**Category**	**Estimate**	**StdError**	**DF**	**t Value**	**Pr>[t]**	**N**	**Pr>F***
Gender	InterceptMale	6.3982	0.1243	537	51.49	<.0001	539	<.0001
	Female	-0.9648	0.1991	537	-4.85	<.0001	539	
Race/Ethnicity	InterceptWhite	6.1399	0.1448	534	42.41	<.0001	539	<.0001
	Asian	-0.4919	0.2484	534	-1.98	0.0482	539	
	Internat'l	1.0139	0.3893	534	2.60	0.0095	539	
	Other	0.2744	0.3062	534	0.90	0.3706	539	
	URM	-0.9786	0.3211	534	-3.05	0.0024	539	
MAIForm	InterceptOE	4.3546	0.1749	537	24.90	<.0001	539	<.0001
	MC	2.2585	0.2036	537	11.09	<.0001	539	
Course	Intercept1920	6.6382	0.1287	537	51.60	<.0001	539	<.0001
	1910	-1.3496	0.1904	537	-7.09	<.0001	539	
Intercept		2.7961	0.2037	535	13.73	<.0001	537	
Pretest MAI		0.6030	0.03494	535	17.26	<.0001	537	
Intercept		2.6038	0.9654	144	2.70	0.078	146	
EngSEsuccPost		0.6919	0.1794	144	3.86	0.0002	146	
Intercept		2.3210	1.0788	140	2.15	0.0332	142	
EngSEcompPost		0.7008	0.1878	140	3.73	0.0003	142	
Intercept		2.4557	1.0409	140	2.36	0.0197	142	
MathAppSEpost		0.6612	0.1768	140	3.74	0.0003	142	
Intercept		3.8921	0.3295	536	11.81	<.0001	538	
Final grade		0.7432	0.1104	536	6.73	<.0001	538	

*Indicates overall significance for categorical variables.

Table 5: Mathematics Applications Inventory Pretest to Posttest Gain Predictors

Effect	**Category**	**Estimate**	**StdError**	**DF**	**t Value**	**Pr>[t]**	**N**	**Pr>F***
Gender	InterceptMale	0.8685	0.1125	535	7.72	<.0001	537	0.0039
	Female	-0.5209	0.1799	535	-2.89	0.0039	537	
Race/Ethnicity	InterceptWhite	0.6736	0.1318	532	5.11	<.0001	537	0.5121
	Asian	-0.2096	0.2258	532	-0.93	0.3538	537	
	Internat'l	0.4547	0.3537	532	1.29	0.1993	537	
	Other	-0.00689	0.2798	532	-0.02	0.9804	537	
	URM	0.06838	0.2918	532	0.23	0.8148	537	
MAIForm	InterceptOE	0.9784	0.1732	535	5.65	<.0001	537	0.0359
	MC	-0.4231	0.2012	535	-2.10	0.0359	537	
Course	Intercept1920	0.5939	0.1197	535	4.96	<.0001	537	0.3797
	1910	0.1561	0.1776	535	0.88	0.3797	537	
Intercept		2.7961	0.2037	535	13.73	<.0001	537	
Pretest MAI		-0.3970	0.03494	535	-11.36	<.0001	537	

Intercept		0.8443	0.2012	102	4.20	<.0001	104	
EngSEsuccGain		0.1024	0.2347	102	0.44	0.6636	104	
Intercept		0.9510	0.2041	99	4.66	<.0001	101	
EngSEcompGain		0.3593	0.1812	99	1.98	0.0501	101	
Intercept		0.8826	0.1952	99	4.52	<.0001	101	
MathAppSEGain		0.3761	0.1812	99	2.07	0.0406	101	
Intercept		0.5187	0.3060	534	1.69	0.0907	536	
Final grade		0.04963	0.1026	534	0.48	0.6286	536	

*Indicates overall significance for categorical variables.

These bivariate analyses demonstrate several interesting patterns. Consistent gender effects are present, as being female is associated with lower MAI scores at both pretest and posttest and lower average gain. Some differences by race/ethnicity are also present, with underrepresented minority students obtaining lower average MAI scores, and International students obtaining higher average scores, relative to White students, at both pretest and posttest. In terms of course effects, being enrolled in 1910 is associated with lower MAI scores at both pretest and posttest. These analyses also indicate a positive association, at both pretest and posttest, between the self-efficacy measure for engineering curriculum success, engineering curriculum completion, and math applications.

The influences on MAI gain scores will be explored further in the full regression model presented below. The self-efficacy measures are not included in this model, as they are expected to be associated with MAI performance, but not to be a causal influence on MAI performance. The relationships among these self-efficacy measure, MAI performance, and course performance will be explored further in our future work on this project.

Table 6 reports the results of the General Linear Model regression analysis, with the propensity-score-based quintile matching, testing for a course effect on MAI gain while controlling for the other significant variables identified. An analysis of variance was initially performed with all variables expected to influence MAI gains, including course enrollment, MAI pretest score, MAI form, quintile placement, gender, race/ethnicity, and interaction terms for MAI form by course, quintile by course, quintile by pretest score, gender by pretest score, race/ethnicity by pretest score, gender by course, and race/ethnicity by course. Only those variables found to be significant in this initial analysis are included in the final model reported below.

Table 6: Full Regression Model for Estimated Effects on Mathematics Applications Inventory Pretest to Posttest Gains (N=519)

Coefficients	**Category**	**Estimate**	**Std Error**	**t Value**	**Pr >[t]**
Intercept		3.28472***	0.54180	6.063	2.58e-09
Course	1920	-.28499	0.26222	-1.087	0.277606
MAI pretest		-.73380***	0.10644	-6.894	1.58e-11
Quintile 2		0.22732	0.59923	0.379	0.704578
Quintile 3		0.25527	0.64525	0.396	0.692551
Quintile 4		-0.03663	0.65511	-0.056	0.955429
Quintile 5		-1.05020	0.71478	-1.469	0.142367
MAI Form	OE	-1.24304***	0.20549	-6.049	2.79e-09
Gender	Male	0.82228*	0.40207	2.045	0.041349
Race/ethnicity	Internat'l	1.18335***	0.33182	3.566	0.000396
	Other	0.68335*	0.27033	2.528	0.011772
	URM	0.16070	0.29388	0.547	0.584746
	White	0.73399**	0.22539	3.257	0.001201
Pretest*Quintile	Quintile 2	0.07662	0.12366	0.6200	0.535806
	Quintile 3	0.12281	0.12526	0.980	0.327348
	Quintile 4	0.23611	0.12192	1.937	0.053345
	Quintile 5	0.38385**	0.12313	3.117	0.001926
Pretest*Gender	Male	-0.13760	0.07439	-1.850	0.064921
Course*Gender	1920*Male	0.99107**	0.32168	3.081	0.002173

Multiple R-squared=0.3339; Adjusted R-squared=0.3107

*Significant at the .05 level; ** significant at the .01 level; ***significant at the .001 level

As expected, the MAI pretest has a significant negative effect on the MAI gain from pretest to posttest, since higher pretest scores leave less available gain. The negative estimate obtained for the open-ended version of the MAI indicates that the higher raw gains obtained on the open-ended version (Table 2) disappear once the pretest scores and the other variables are controlled for. The positive effects for male students indicate the significantly higher average MAI gains obtained overall; and the effect of the interaction of course by gender indicates that these gender effects are amplified in the 1920 course. As for the race/ethnicity effects, we observe positive effects on MAI gain associated with being International, White, or Other, relative to being Asian which is used as the referent in this analysis. As for the analysis by quintiles, there is no significant effect on gain associated with being in any one of the five quintiles until the interaction of pretest score and quintile placement is considered. For this interaction, being in the fifth (or most prepared) quintile is positively associated with MAI gain. However, our main variable of interest to test our treatment effect, course enrollment, does not show a significant difference in our model.

Discussion and Next Steps

These findings have, above all, demonstrated the difficulty of detecting treatment effects with imperfect controls on the group experience. Although we have not been able to support an overall treatment effect for the workshop intervention in the *Calculus for Engineers* course, we are eager to further explore several tracks more in-depth. One is the gender differences in MAI performance across the two courses which are demonstrated here and warrant further investigation. A second is the relationships among the self-efficacy measures, MAI performance, and course performance. A third is a closer look at the concurrent curricular experiences of our respondents. In particular, those enrolled in the second course in the engineering mathematics sequence are far more likely to be concurrently enrolled in a physics course. We are eager to explore the effects of that type of additional curricular experience applying mathematics to physical phenomena on MAI performance.

With these further questions to explore, our work in assessing the impact of the collaborative problem-solving workshops in our first-semester engineering calculus course on students' applied mathematical problem-solving skills and self-efficacy perceptions continues. We are also continuing in our efforts to ascertain the value of the Mathematics Applications Inventory and the self-efficacy scales we are employing for detecting learning and attitudinal outcomes resulting from this curricular innovation and others like it.

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