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Evolution of a First-Year Engineering Course

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Amy J. Moll is a Professor of Materials Science and Engineering and Dean of the College of Engineering at Boise State University. Amy received a B.S. degree in Ceramic Engineering from University of Illinois, Urbana in 1987. Her M.S. and Ph.D. degrees are in Materials Science and Engineering from University of California at Berkeley in 1992 and 1994. Following graduate school, Amy worked for Hewlett Packard in San Jose, CA and in Colorado Springs, CO. She joined the faculty at Boise State as an Assistant Professor in Mechanical Engineering in August 200. Along with Dr. Bill Knowlton, Amy founded the Materials Science and Engineering Program at BSU and served as the first chair. In February 2011, Amy was became Dean of the College of Engineering. Amy's research interests include microelectronic packaging, particularly 3-D integration and ceramic MEMS devices. Amy especially enjoys teaching the Introduction to Engineering and Introduction to Materials Science and Engineering courses as well as engineering outreach activities.

Evolution of a First-Year Engineering Course

Background

The first-year engineering course at Boise State University has evolved significantly over the past decade as a result of continuous improvement with a particular focus on student retention. The course was originally created in 1999-2001 as an "Introduction to Engineering" course in order to recruit students to one of the fields of engineering, by introducing those fields of engineering as topics across the semester. Over the first ten years, the course continued that introductory-to-field focus while also introducing a significant design element solving open-ended engineering problems. As a result of a five-year grant aimed toward improving first-year retention, the first-year course was substantially revised in 2013 to focus on developing mathematics skills, based on the work of Klingbeil and colleagues[1–3]. This paper describes these most recent modifications to the course and presents results from students who took the modified course as they moved forward in their academic careers and took second year mathematics and science courses. We collected data both in the form of grades and measurements of students' self-efficacy to explore how increasing mathematical content in the first-year engineering class can improve students' performance in both co-enrolled and subsequently enrolled mathematics and science courses.

The work described in this paper was funded via the Idaho STEM Talent Expansion Program (STEP) grant, awarded in 2010. At the start of the grant, an external advisory board was created, led by the Provost and including the Deans of Engineering and Arts & Sciences, and several community members interested in increasing the science, technology, engineering and mathematics (STEM) workforce in this state. The advisory board met twice annually, and reviewed the targets of the grant each time they met. The grant's objective was explicitly focused on first-year success:

> "*The Idaho STEP Program represents an institutional plan and commitment to first year success for incoming STEM majors at Boise State University. It is designed for student success by (1) integrating new student orientation with math assessment and learning, (2) linking STEM faculty educational training with STEM freshman learning communities and with orientation, and (3) integrating and expanding, based on research best practices, existing programs such as learning communities, undergraduate research, and faculty development. The program targets all first year students for success and is expected to have a significant impact on at-risk students. Students at-risk for not earning or completing a STEM degree include those who are underprepared in math, those with financial need, Hispanic students, women, and students with low self-efficacy*."

The grant was motivated by significant issues present at that time concerning STEM student retention, caused in part by rapid STEM enrollment growth. STEM enrollment went from 1,983 enrolled students in fall, 2005, comprising 10.7% of the university's enrollment to a level of 3,778 in fall, 2014, comprising 19.5% of the university's enrollment. This rapid growth caused the offerings in numerous STEM courses, to be expanded. This particularly affected the department of mathematics, causing many additional sections of Pre-Calculus, Calculus I and II and beyond being added on an as-needed basis. This resulted in a situation where the instructor and department focus was more on surviving growth instead of optimizing the learning environment. Pass rates varied widely from instructor to instructor, creating a strong sense in the minds of students and faculty in other departments that success in calculus was dependent on luck: "Who you took" mattered more than "What you learned." The average pass rate across the 2005-2006 academic year for Calculus I was approximately 51%[4], and the STEM first-time, full-time retention in 2007-8 was 57%.[5]

As a result of the need, the grant team, which included the Chair of Mathematics, focused strongly on the situation in mathematics. The grant team developed a two-pronged approach focusing first, on faculty development and course coordination; this is described elsewhere[6,7], and second, on modifying the Introduction to Engineering curriculum so as to add to the toolkits of engineering students and thereby help them "survive" mathematics. We conducted a literature search, looking for programs with data showing positive results. At the 2011 ASEE conference in Vancouver BC we noted the success of the Wright State Math Model[8], and began considering using this model for our Introduction to Engineering class. The Wright state model was differentiated from other introduction to engineering courses in that they had data suggesting that their students who had taken this course, EGR 101, performed better in Calculus I and exhibited higher graduation rates in both the College of Engineering and Computer Science (CECS) and Wright State University as a whole.[9]

These data were presented to the STEM grant's advisory board in January, 2013 and the decision was made to move forward with a pilot implementation of the Wright State Model in fall, 2013 as an additional alternative for the project based Intro to engineering class.

There were substantial differences in the course goals between the project based class and the Wright State model. The project-based class had the following curricular goals:

> Critical thinking design-oriented engineering experiences that introduce the professions of civil, electrical/computer, mechanical and materials science and engineering.
>
> Professional skill development including teamwork, computer based tools, oral and written communication, advisement.

The Wright State Model had the following stated goals[10]:

- Solve problems involving applications of algebra and trigonometry in engineering.
- Solve problems involving applications of vectors and complex numbers in engineering.
- Solve problems involving applications of systems of equations and matrices in engineering.
- Solve problems involving applications of derivatives in engineering.
- Solve problems involving applications of integrals in engineering.
- Solve problems involving applications of differential equations in engineering.
- Use MATLAB to solve a variety of introductory engineering mathematics problems.
- Conduct a variety of physical experiments using engineering laboratory equipment.
- Write proper technical abstracts for engineering laboratory assignments.

While the project-oriented class aims to give the student an open-ended design experience, the Wright State class aims to bolster students' math skills, specifically within the context of engineering problems.

The project-oriented class contained four modules, three of them lasting about two weeks each with the fourth being considerably longer: (1) consumer product testing / design of experiments, (2) a manufacturing module, (3) a module on circuits and finally (4) a 7-week long renewable energy module. In the last module, after exploring energy and renewable energy, students designed and built a small-scale generator; magnets, magnet wire and a drive shaft were the only materials provided to them. They also designed, fabricated and tested wind turbine blades using a standard pre-fabricated generator for testing. Once each sub-assembly was complete, they integrated the turbine blades with the generator to produce a small-scale wind turbine. Final testing was conducted in the wind tunnel. Students were required to analyze their design decisions and report results several times throughout the project. This module was new to the 2013-2014 project oriented class, and was received with much enthusiasm; several students built their own generator at home.

The Wright State offering was a clone of the course offered at Wright State University, including textbook[11], homework, lecture schedule and lab/recitation activities. The lectures consisted of working math examples and having the students work team solutions to problems. There were two 75 minute lectures per week. The laboratories were led by upper division TAs, and were scheduled for two 75 minute meetings per week. The first meeting was used to have the students execute an experiment and collect data. The experiments were designed to motivate the students to use the math techniques from the lecture to analyze the data. The second meeting was a recitation where the students worked through math and MATLAB homework in small groups.

Procedures

In summer of 2013, the Wright State class was prepared. During an intensive four-week period, the course instructor worked with a team of six teaching assistants to purchase the materials needed for the in-class experiments, and conduct dry-runs of each experiment. In addition, the course instructor and TAs developed a deeper understanding of MATLAB which is an essential component of the Wright State course.

During spring and summer of 2013, students were randomly enrolled in either of the two three-credit Introduction to Engineering classes, which were differentiated only by section number. Students did not know in advance that there were any differences between sections. A total of 182 students enrolled in the project-oriented class, while 95 enrolled in the Wright State class. However, during the semester, students became aware of the differences, wondering "Why do we have to do math?" and, "Why can't I be in the fun section?" The two-mode model continued in spring, 2014, with 105 students enrolled in the project oriented class and 35 enrolled in the Wright State class. A decision was made to consolidate the courses into one hybrid model that took effect in fall of 2014; it is briefly described in the section below. This paper reports primarily on the results of the fall 2013 offerings with limited data on the fall 2014 adoption of the hybrid class.

Continuous Improvement Effective Fall 2014

During the 2013-2014 year there was confusion among the entering freshman students because there were two varieties of Introduction to Engineering classes being offered. Because the Wright State clone was more rigorous mathematically it quickly gained the reputation of being the hard version while the students viewed the design-based class as being the fun version. The end result was that many students switched to the design based version in spring of 2014.

A decision was made to consolidate the two courses for the 2014 – 2015 academic year so that there was only one version of first-year engineering offered, a hybrid between the Wright State model and the design-focused engineering course. The changes are summarized below. The objectives for these changes were to maintain some design-orientation to the course, while adding more rigor with a portion of the math and MATLAB programming included with the Wright State clone implementation. One of the overarching goals was to allow students to explore a design problem through a lab activity, then to analyze the problem mathematically and/or with MATLAB.

The traditional design of experiments activity, consumer product testing, was replaced with a trebuchet where students could modify several variables to maximize the throwing distance. Problems in achieving repeatable results, lack of tools to measure launch angle and the complexity of math analysis motivated a change to a simpler approach for spring 2015. The trebuchet was replaced with a track system to launch a projectile. This simpler approach was more repeatable and allowed students to use MATLAB to predict the ramp height needed to launch the projectile a given distance.

The manufacturing module was replaced with a near 2-dimensional truss module. Students built several truss configurations and tested them to failure. They explored different construction members, e.g. craft sticks vs. wire, to gain a better understanding of tension and compression forces. They also completed a mathematical analysis of the forces at a joint, using an approach many will later see in statics, and conducted a MATLAB analysis to quantify the force in each member of the truss.

The final open-ended design project of a wind turbine was kept intact. It met the goals of open-ended design as well as utilizing interesting mathematical analyses. In addition the students enjoy this project.

Results

The grade point averages of students as they moved on in their curricula were monitored as well as the grades in their Calculus I and II and Physics courses. Results for grades from the 2013-2014 school year are reported below. Additional data came from the Longitudinal Assessment of Engineering Self-Efficacy (LAESE) survey [12], which was administered to all students once for the fall of 2013 cohort of students and twice at the beginning and end of the class to the fall 2014 students. This survey is validated with undergraduate engineering students to assess their self-efficacy, and self-efficacy has in turn been established as a strong predictor of student success in engineering.[13]

Grades

As mentioned earlier, our primary goal for these modifications to the first year engineering course was to increases students' ability to succeed in their math courses. To assess the effectiveness of the changes to the course, we examined students' grades in other courses required for majoring in engineering.

Calculus I

Figure 4 and Table 1 compare the grades for students either co-enrolled or enrolled in Calculus I after completing either the Project-Based or Math-Focused versions of the First-Year Engineering course in the fall of 2013. Comparing the distributions, a significantly higher proportion of students in the Math-Focused class earned a grade of A or B compared to the project-based class, while the proportion of students receiving D and F grades remained virtually unchanged.

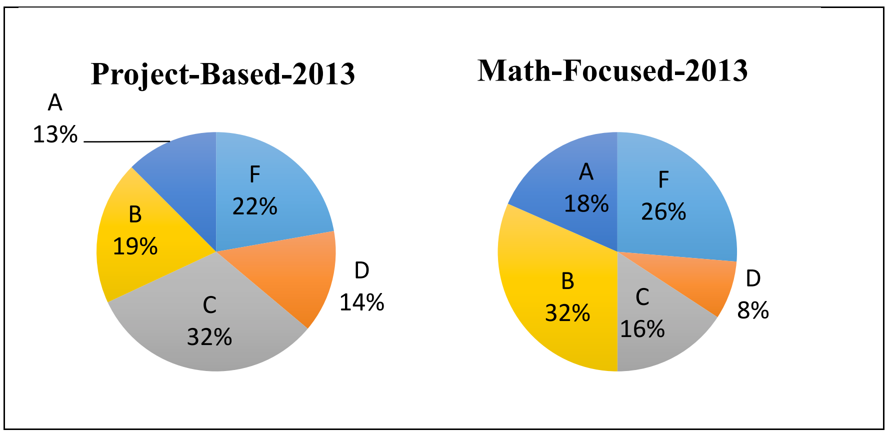

Figure 1: Calculus I grade comparison

Using an independent T-test, we determined that the difference between the means of the two groups is not significant. However, a higher proportion of students in the mathematics-focused section of first-year engineering earned an A or B in their Calculus I class than expected when compared to students enrolled in the standard first-year engineering course, and we found this difference to be statistically significant using a χ^2 test ($p<0.05$).

Table 1: Calculus I grade comparison

	Mean Grade	**Median Grade**		**A or B**		
				No	Yes	**Total**
Project-Based	1.84	2.0	Count	49	34	83
			Percentage of Section	59%	41%	
Math-Focused	2.10	2.5	Count	19	29	48
			Percentage of Section	40%	60%	

Calculus II

Figure 5 and Table 2 compare the grades for students either co-enrolled or enrolled in Calculus II after completing either the Project-Based or Math-Focused versions of the First-Year Engineering course in the fall of 2013. Both the charts and the table indicated very little difference in mean grade or the distribution of the grades between the participants in the different versions of the course.

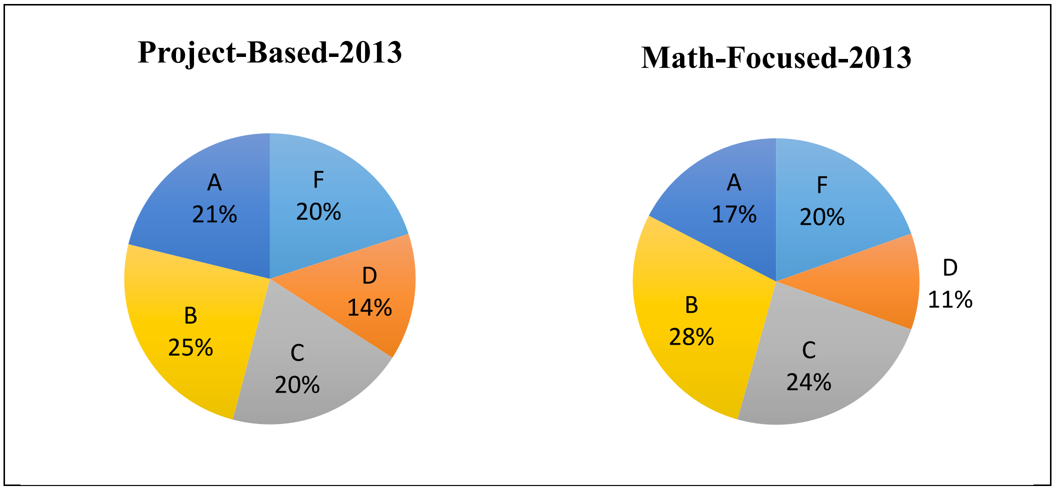

Figure 2: Calculus II grade comparison

Table 2: Calculus II grade comparison

	Mean Grade	Median Grade		A or B: No	A or B: Yes	Total
Project-Based	2.09	2.3	Count	46	39	85
			Percentage of Section	54%	45%	
Math-Focused	2.11	2.0	Count	22	19	41
			Percentage of Section	54%	46 %	

Physics

Figure 6 and Table 3 compare the grades for students either co-enrolled or enrolled in Physics I after completing either the Project-Based or Math-Focused versions of the First-Year Engineering course in the fall of 2013. Students enrolled in math-focused section had slightly higher mean and median grades in Physics I and were more likely to receive and A or B in the class, but the differences were not statistically significant.

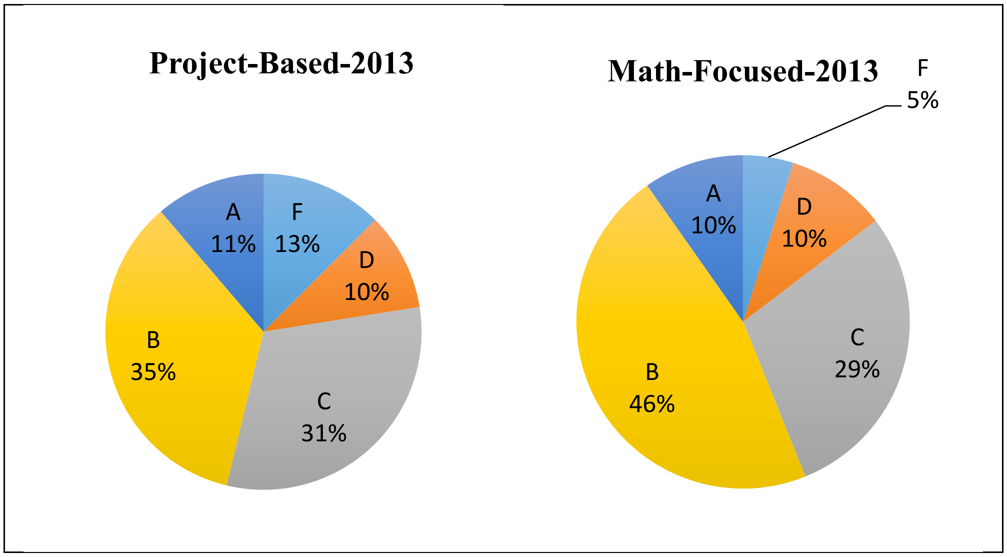

Figure 3: Physics grade comparison

Table 3: Physics grade comparison

	Mean Grade	Median Grade		A or B		
				No	Yes	Total
Project-Based	2.21	2.3	Count	43	37	80
			Percentage of Section	54%	46%	
Math-Focused	2.51	2.7	Count	17	22	39
			Percentage of Section	44%	56%	

Self-Efficacy

The LAESE includes multiple subscales designed and validated to measure difference aspects of students' self-efficacy[12]. For this research we utilized three different subscales of the LAESE instrument: Engineering Self-Efficacy 1 (ESE1), Engineering Self-Efficacy 2 (ESE2) and Math Outcome Expectations (MATH). Tables 4 through 6 show comparisons of these subscales for different groups of students that we assessed as part of this work.

Table 4 shows the differences in the Self-Efficacy measurements for the three aforementioned subscales, comparing the Project-Based and Math-Focused sections of the fall 2013 course. Students in the Math-Focused sections scored lower for each of the three subscales, with only the drop in the Engineering Self-Efficacy 2 (ESE2) shown to be statistically significant using an independent samples t-test.

Table 4: Comparison of Self-Efficacy scores for Project-Based and Math-Focused sections

	SECTION	N	Mean	Std. Deviation	Std. Error Mean	Mean Difference
ESE1	Project-Based	88	4.70	1.04	0.11	-0.17
	Math-Focused	34	4.53	0.97	0.17	
ESE2	Project-Based	88	5.15	0.71	0.08	-0.39*
	Math-Focused	34	4.75	0.72	0.12	
MATH	Project-Based	88	4.92	1.03	0.11	-0.19
	Math-Focused	34	4.74	0.91	0.16	

*Difference is statistically significant ($p<0.05$)

Table 5 shows the differences in the Self-Efficacy measurements for the three aforementioned subscales, comparing the Project-Based sections of the fall 2013 course with the current as of fall 2014 version of the course that has a stronger emphasis on mathematics. Students in the 2014 sections scored lower for both of the engineering self-efficacy subscales and slightly higher on the mathematics subscale. Again, only the drop in the Engineering Self-Efficacy 2 (ESE2) was statistically significant using an independent samples t-test.

Table 5: Comparison of Self-Efficacy scores between Project-Based 2013 and 2014 Classes

	YEAR	N	Mean	Std. Deviation	Std. Error Mean	Mean Difference
ESE1	2013	119	4.62	1.02	0.09	-0.10
	2014	117	4.52	1.10	0.10	
ESE2	2013	119	5.11	0.78	0.07	-0.39*
	2014	118	4.72	0.83	0.08	
MATH	2013	119	4.89	1.01	0.09	0.20
	2014	118	5.09	0.93	0.09	

*Difference is statistically significant ($p<0.05$)

Table 6 shows the differences in the Self-Efficacy measurements between the beginning and the end of the Fall 2014 semester. Again there is a small and statistically not significant drop in the engineering self-efficacy measurements utilizing paired samples t-tests. However, there is a small but statistically significant increase in the mathematics self-efficacy of the students over the course of the semester, again utilizing a paired samples t-test.

Table 6: Comparison of Pre and Post Self-Efficacy Scores for Fall 2014 class

		Mean	N	Std. Deviation	Std. Error Mean	Mean Difference
ESE1	Post	4.60	103	1.10	0.11	-0.04
	Pre	4.64	103	0.95	0.09	
ESE2	Post	4.74	104	0.86	0.08	-0.09
	Pre	4.83	104	0.70	0.07	
Math	Post	5.11	104	0.89	0.09	0.17*
	Pre	4.95	104	0.95	0.09	

*Difference is statistically significant ($p<0.05$)

Overall, the LAESE results suggest that changes to the course have slightly shifted students' self-efficacy beliefs, with reduced efficacy beliefs on one of the engineering subscales and increased self-efficacy related to students' ability to be successful in mathematics. The results also suggest that the LAESE may not be the best instrument for assessing the effects of the changes that we are making to the first-year engineering classes, and future work includes exploring other assessment techniques such as utilizing a different instrument, developing our own instrument, or adding qualitative assessment techniques such as open response questions and focus groups to better assess the effectiveness of our first-year engineering program.

Conclusions

The process of improving a first-year engineering course is one of continuous improvement, and we will continue to make changes to this course based on the results described in this paper. While modifying the content of the first-year engineering course at Boise State University to include a stronger emphasis on mathematics content had a small effect on some students' Calculus grades, it did not result in increased success for a majority of the students. This suggests that further work is needed to identify ways to improve the mathematics achievement of first-year engineering students. In addition, due to the shortcomings of the data we presented in this paper, we intend to explore additional quantitative and qualitative techniques to better assess the effects of changes to first-year engineering on our students. As the student cohorts described in this paper progress through their engineering studies, we will explore how their success and persistence compares to earlier cohorts of engineering students.

Although the shifts in self-efficacy scores associated with this project were small, increases in self-efficacy can positively affect students' grades and persistence in university engineering.[13] In addition, although the number of students failing or receiving D grades did not seem to change as a result of the changes made as part of this project, the statistically significant shift towards higher grades for the passing students may increase their tendency to persist in engineering, which we will continue to monitor via tracking graduation rates and persistence in an engineering major.

Anecdotally, the increased analytical focus of the class seems to be encouraging students to take the class more seriously, especially with regards to the inclusion of a final exam. This in turn seems to be helping students develop the general skills that they need to be successful in future engineering classes, such as study skills, the ability to meet deadlines, and perseverance in the face of challenging assignments or topics. We will continue to incorporate math and/or MATLAB with the open-ended design lab activities to illustrate to students the relevance and value of these analyses in the design process.

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