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Assessment of Implementing an Undergraduate Integrated Thermal-Fluids Course Sequence on the Results of the Fundamentals of Engineering Exam (FEE)

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Assessment of Implementing an Undergraduate, Integrated Thermal-Fluids Course Sequence on the Results of the Fundamentals of Engineering Exam (FEE)

Introduction

The purpose of this paper is to assess and analyze the impact that changing from a traditional two-course sequence in Thermodynamics and Fluid Mechanics to a one- or two-course sequence in Thermal-Fluids Systems has had on the performance of engineering students at the United States Military Academy on the Fundamentals of Engineering Exam (FEE). The two courses of interest are MC311: Thermal-Fluid Systems I and MC312: Thermal-Fluids Systems II. Both are taught by faculty members from the Mechanical Engineering program in the Department of Civil and Mechanical Engineering at West Point but taken by students from the Chemical, Civil, Electrical, Environmental, Mechanical, and Nuclear Engineering programs.

In 2003 the department explored the idea of integrating thermodynamic and fluid mechanics topics into a two-course integrated sequence. The original proposal also called for the integration of Heat Transfer into this two-course sequence but that option was later dropped due to the amount of content required.[1] The initial impetus to combining the two courses was two-fold. First, due to the high number of required core courses at the United States Military Academy, several ABET programs outside of the Civil and Mechanical Engineering department desired the ability to increase the course work within their own program by one course, while still obtaining sufficient knowledge of thermodynamic and fluid mechanics principles to pass the FEE. That was an external driver for change. Internally, the Mechanical Engineering program felt that integrating the two topics could create efficiency. Many of the fundamental concepts in each separate course were based on conservation of mass and energy, or losses due to irreversibilities. The increased efficiency gained by teaching Thermodynamics and Fluid Mechanics could then be used to introduce topics not previously covered under the more traditional two courses. The initial process of developing and launching what was originally offered as ME311[2] and ME312[3] was documented in two conference papers published by the Mechanical Engineering faculty members involved in the creation of the courses. For consistency throughout this paper, the courses will always be referred to as ME311 and ME312, despite changing to the MC prefix in 2012.

Since one of the drivers behind implementing the integrated course sequence was reducing the course requirements by one while retaining sufficient content to pass the FEE, it is important to examine any impact the changes have had. Based on an analysis of the results, it is clear that changing to an integrated two-course sequence did not have any significant, negative impact on the FEE results in related topic questions. Furthermore, there was not a significant difference in the FEE results on related questions between students who took ME311 and ME312 and students whose programs only required ME311.

Background

Integrating Thermodynamics and Fluid Mechanics into a single course or sequence of courses is not unique to the United States Military Academy. However, it is not common in Mechanical Engineering programs. A review of the top ten Mechanical Engineering undergraduate programs, according to U.S. New and World Report, indicates that only one school offered an integrated Thermal-Fluids sequence.[4] That school offered the traditional Thermodynamics and Fluid Mechanics courses as well thus not fully switching the curriculum to an integrated method. The authors also examined the curriculum of the two peer service academies' ME programs and found that only the U.S. Naval Academy offered an integrated Thermal-Fluids sequence, while retaining the traditional Thermodynamics and Fluid Mechanics courses in their offerings. The limited availability of integrated thermal-fluids textbooks, compared to the wide availability of Thermodynamics and Fluid Mechanics textbooks, also indicates that the concept of integrating these two topics remains to be widely accepted.

In terms of the population at West Point impacted by the change in curriculum, there are six different programs that previously took both Thermodynamics and Fluid Mechanics. Those programs are listed below in Table 1, along with a summary of which programs decided to take both ME311 and ME312, or just ME311. In addition, the subject areas that those programs take on the FEE are listed as well. As a point of clarification, all cadets enrolled in these programs are required to take the FEE. This policy is unlike other schools, where taking the FEE is optional. Thus, the FEE results serve as an assessment tool for entire programs instead of only assessing those students who opt to take the exam and are likely better performers.

Table 1: Engineering Programs at West Point and Course Requirements

Major:	**MC311 only or MC311/312**	**FEE Requirements**
Chemical Engineering	Both	- Fluid Mechanics and Dynamics - Thermodynamics
Civil Engineering	MC311	- Fluid Mechanics
Electrical Engineering	MC311	N/A
Environmental Engineering	MC311 (MC312 is elective)	- Fluid Mechanics - Thermodynamics
Mechanical Engineering	Both	- Fluid Mechanics - Thermodynamics
Nuclear Engineering (Other on FEE CBT)	Both	- Fluid Mechanics and Dynamics of Liquids - Fluid Mechanics and Dynamics of Gases - Heat, Mass, and Energy Transfer

Implementation and History of the Course Sequence:

From the initial creation of ME311 and ME312, the courses were designed around a case-study approach. This approach was documented in greater detail in the two articles previously referenced, and involved presenting the course content based on an examination of real-world systems. [2,3] The case-study approach was used to both place the theory in context to stimulate student learning and to increase student awareness of critical systems that they may encounter as engineers and officers in the U.S. Army. For some topics like energy, the content was presented in a truly integrated manner. For example, the 1st Law of Thermodynamics and the traditional mechanical energy equation are presented together and then later used to further develop the Bernoulli equation. The losses associated with the 2nd Law of Thermodynamics can be compared to pipe losses. However, another main advantage of integrating the topics and using the case study approach, was to demonstrate how multiple disciplines are required to analyze real-world systems. A more detailed explanation of the course content appears in a previous article titled "Teaching the Fundamentals of Thermodynamics and Fluid Mechanics through an Integrated Systems Approach", in the 2006 ASME International Mechanical Engineering Congress and Exposition proceedings. A list of the content in each thermal-fluids course appears in Table 2

The initial textbook for the course was Çengel and Turner's Fundamentals of Thermal-Fluid Sciences, 2nd Edition, published by McGraw Hill. This textbook was supplemented with additional, custom material for ME312. The team that designed ME311 selected this text because, at the time, it was the only commercially available text that covered the majority of the required material. However, the textbook did not completely achieve the degree of integration desired. For example, chapter 5 of the text details the First Law of Thermodynamics, while chapter 12 covers the Mechanical Energy equation. The text did show how the traditional Fluid Mechanics energy equation was derived from the First Law of Thermodynamics, however. In 2008, the third edition of this text was used, but only for one academic year.

Changes in the latest edition of the text eliminated several topics from the textbook that were important for the courses. For example, the revision removed content for lessons on the vapor power cycle, refrigeration, and psychrometrics and placed some of that material in an online format. These changes forced the faculty to add more material to a supplemental, custom text creating a supplemental text that was actually quite large and defeated the purpose of seeking one, integrated textbook. As a result, in 2009 the faculty selected two textbooks for the course. They were Çengel and Bole's Thermodynamics: An Engineering Approach, 6th Ed and Çengel and Cimbala's Fluid Mechanics: Fundamentals and Applications, 1st Ed. The advantages to using these texts were that they retained much of the symbols and nomenclature as the previous thermal-fluids textbook, and provided students with a more permanent reference than the use of the supplemental text did. However, the separation of Thermodynamics and Fluid Mechanics into two separate books appeared contrary to the course message of an integrated approach.

In 2009, one of the faculty members with extensive experience teaching ME311, wrote a textbook tailored to both the integrated approach to the two topics and to the specific structure

and content of ME311 and ME312. This textbook was originally titled West Point ME311, ME312 Thermal-fluid Systems I and II and was later changed to West Point Thermal-fluid Systems. The textbook had an accompanying reference manual that contained property tables and charts. Both books were first used in the Spring semester of academic year 2010 and remain in use at the writing of this paper. While the course content has changed slightly over the ten years that ME311 and ME312 have been offered, in general the content breakdown remains unchanged and appears in Table 2. The topics marked with an asterisk represent areas that were added after the topics were integrated and were not offered when Thermodynamics and Fluid Mechanics were separate courses.

Table 2: Breakdown of Topics in ME311 and ME312

ME311 Topics	ME312 Topics
• Ideal Gas Law • State Principle and Properties • Hydrostatics and Buoyancy • Surface Tension and Capillary Action* • Reynolds Transport Theorem • Conservation of Mass • Conservation of Energy • Losses and Irreversibilities • Cycles • Vapor Power Cycles • Internal Flow • Vapor Compression Refrigeration Cycles • Psychrometrics	• Dimensional Analysis and Similarity • Introduction to Experimental Methods • External Flow • Differential Approach to Conservation of Mass and Momentum • Navier-Stokes Equations • Exergy* • Internal Combustion Engines (Otto and Diesel Cycles) • Gas Turbine Engines (Brayton Cycle) • Compressible Flow

* Represent topics added after the courses were integrated

Other Factors Affecting FEE Results

In addition to the implementation of the Thermal-Fluids course sequence, there are other factors that had the potential to affect the results of the FE Exam. Unrelated to this curriculum change, in 2006 the department implemented mandatory FEE review sessions as part of a seminar course in Mechanical Engineering. This course, titled ME400, was only required for those in the Mechanical Engineering program at West Point, which is just one portion of the total FE exam population. However, it is important to note that this change had the potential to increase the pass rates of at least a subset of the total student population in question.

Results

Since the FE exam has changed over the years affected by the course changes to ME311 and ME312, simply examining exam pass rates before and after the curriculum change was insufficient. Instead, a comparison between the pass rates of students affected by the curriculum changes to the national pass rates was more appropriate. The results of that examination appear in Figure 1.

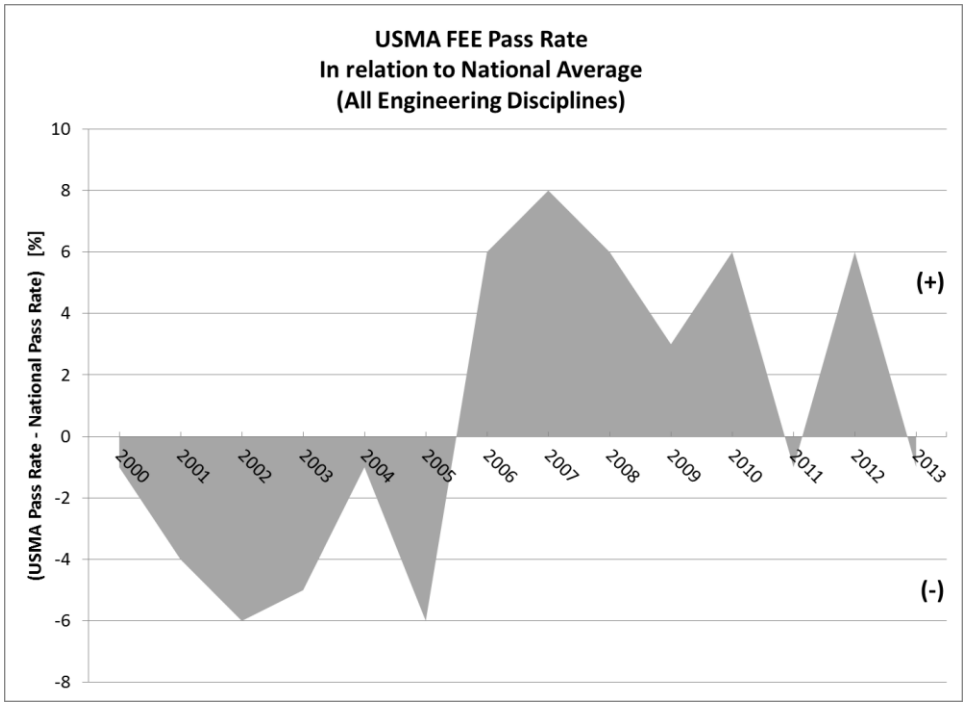

Figure 1: FE Results Compared to National Average

At first glance, it does appear that there is a general improvement in the pass rates of all engineering students at West Point that coincides with the curricular changes incorporating ME311 and ME312 and eliminating the traditional Thermodynamics and Fluid Mechanics courses. In the six years prior to 2006, the results of the institution were consistently below the national average pass rate. However, in the seven years after 2006, the scores were almost exclusively higher than the national average. The two years that they were not higher, in 2011 and 2013, feature only a minor negative delta.

To determine the extent that the changes to ME400 described above could have impacted these results, the authors conducted a closer examination of the results before and after 2006. In Figure 2, the FEE results broken down by engineering discipline are compared to national average. This figure only includes those disciplines who took both ME311 and ME312 since those students received instruction on the same content before and after the curricular changes. The dark grey bars represent the Mechanical Engineering majors. Their results were actually predominantly positive before the changes in 2006 and therefore cannot contribute greatly to the improved trends after 2006 evidenced in Figure 1.

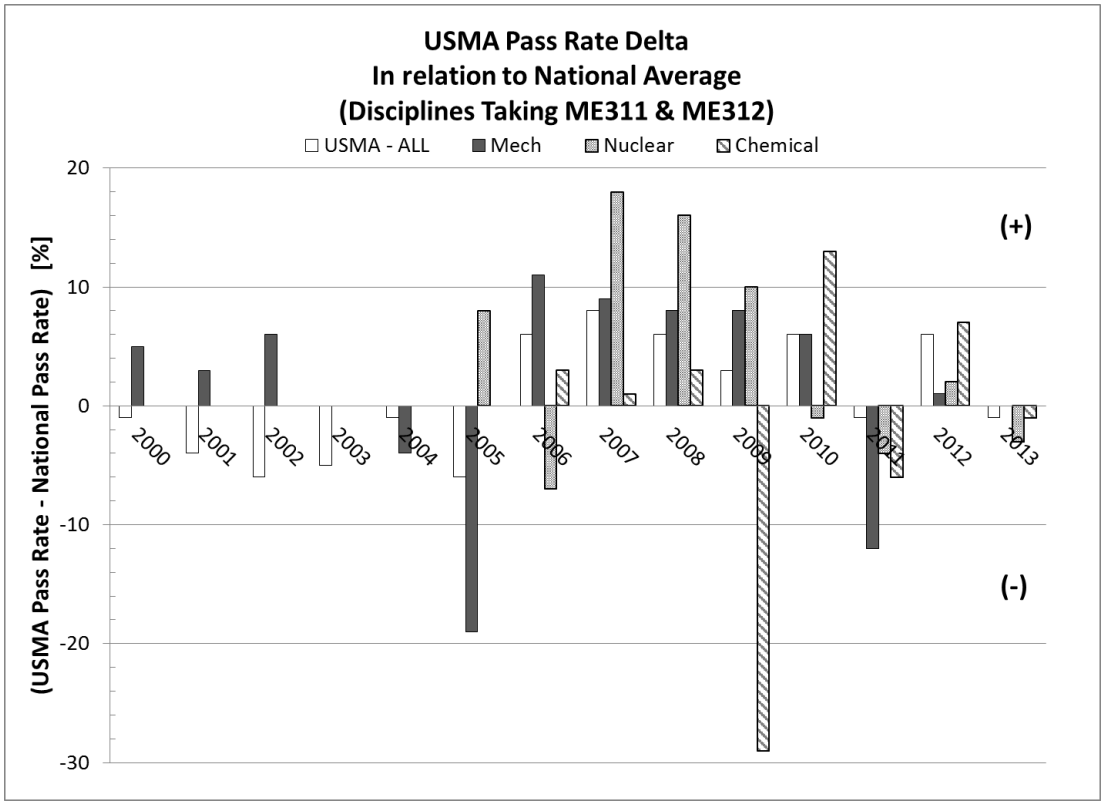

Figure 2: FEE Results Compared to National Average by Discipline

While it was valuable to examine overall trends, these results were subject to a variety of other factors unrelated to Thermodynamics or Fluid Mechanics. Therefore, to gain an even better understanding of the impact that integrating these two topics had, the authors analyzed the results on the FE exam in the areas directly related to these two topics. There were two goals for this analysis. The first was to determine if there was any significant difference in results before the integration and after. The second was to determine if there was any significant difference in FEE results after the integration between those students who took both ME311 and ME312 and the students in programs that elected to only take ME311.

To test the effectiveness of the institution of the ME311 – ME312 sequence versus the Thermodynamics – Fluid Dynamics the authors conducted a statistical analysis of the Fundamentals of Engineering Exam (FEE) Fluids and Thermodynamics scores prior to and after the course revision. The test for each case used a 95% confidence level for the following questions and hypotheses:

- Did changing to integrated courses affect the mean of the normalized percentile of USMA's Thermodynamics and Fluids score on the FEE from 2004 - 2015?
  - Null Hypothesis: $H_0: \mu_{Original} = \mu_{ME311}$
  - Alternate Hypothesis: $H_a: \mu_{Original} \neq \mu_{ME311}$

- Was there a significant difference for majors who were required to take ME311 and ME312 on the mean of the normalized percentile of USMA's Thermodynamics and Fluids score on the FEE?
    - Null Hypothesis: $H_0: \mu_{ME311\ and\ ME312} = \mu_{ME311}$
    - Alternate Hypothesis: $H_a: \mu_{ME311\ and\ ME312} \neq \mu_{ME311}$

The authors compiled the scores for each year from 2004 to 2015 and calculated USMA's percentile score versus the national average to account for any changes in the test, and analyzed the scores using MATLAB's Hypothesis testing, ANOVA analysis and boxplots to determine any correlation. To further segment the data, the data was separated based on the test taken and individual majors. Between the implementation of the computer-based testing and 2013, the test was structured in such a way that the morning session was generic and the afternoon session was discipline-specific. As a result, it was necessary to examine the test results for the two separate portions. For the AM portions of the test all of the majors were combined because the questions were all the same between sections (prior to 2013), and tested the PM sections based on the test taken (Mechanical vs General). The hypothesis testing determines if the mean percentile was significantly affected by the change. Additionally, the authors conducted an ANOVA to display the differences from the expected value of the test scores based on a linear model of the data and the actual data.

Examples of the results for this analysis appear below in Figure 3. The figure shows the boxplots for the delta between West Point's FEE results on the Fluid Mechanics questions on the PM portion of the General exam and the national average for those questions. The data for the left boxplot is for those students who take ME311 only on the right side for those students required to take ME312 as well.

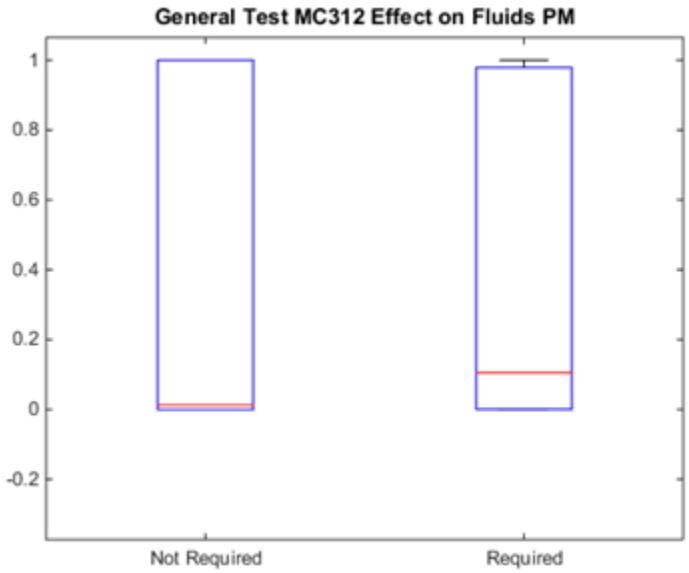

Figure 3: Boxplot of Data for Fluid Mechanics Results on PM Test

This procedure was repeated many times for multiple data sets. To publish the results of all of this analysis would consume excessive space. A summary of the analysis appears in Table 3. What is quickly evident from this chart is that there were few cases in which the null hypothesis was rejected. In other words, there was not enough evidence to show that switching from teaching Thermodynamics and Fluid Mechanics as separate courses to teaching them in an integrated manner had much impact of statistical significance on related FE results. What was perhaps more surprising was that there was a similar lack of statistical difference between the results on related topics between those students who took ME311 and ME312 after the changes and those that only took ME311.

Table 3: Summary of Hypothesis Testing

Hypothesis:	Test Data	Result
Results were same before and after integrated courses	Thermodynamics questions on AM test	Accept
	Fluids questions on AM test	Reject
	General test PM portion Thermodynamics questions	Accept
	General test PM portion Fluids questions	Accept
	Mechanical test PM portion Thermodynamics questions	Accept
	Mechanical test PM portion Fluids questions	Accept
	Combined PM portion Thermodynamics questions	Accept
	Combined PM portion Fluids questions	Reject
Results are same if student takes MC311 and MC312 or just MC311	Thermodynamics questions on AM test	Reject
	Fluids questions on AM test	Accept
	General test PM portion Thermodynamics questions	Accept
	General test PM portion Fluids questions	Accept
	Mechanical test PM portion Thermodynamics questions	Accept
	Mechanical test PM portion Fluids questions	Accept
	Combined PM portion Thermodynamics questions	Reject
	Combined PM portion Fluids questions	Accept

Discussion of Results

What is apparent about the results is that the change to an integrated Thermal-fluids sequence had no statistical impact on FEE results for questions related to Thermodynamics. In both cases that the data led to a rejection of the null hypothesis, the results on questions related to Fluid Mechanics shows a statistically significant improvement after the change to an integrated approach. These results corroborate that changing to the Thermal-fluids courses at a minimum, did no harm, and actually demonstrated some benefit related to Fluid Mechanics.

What is somewhat surprising is that there was little difference in the results of the students who took ME311 and ME312 and those that only took ME311. Moreover, the two areas where the hypothesis was rejected were both related to Thermodynamics and both reflected a decrease in performance for those taking both courses. This anomaly appears to have more to do with the overall success of those programs not taking ME312 than to anything directly related to the courses themselves. For example, in Figure 5, it is evident that students in the Civil Engineering and Electrical Engineering programs did very well on the FEE, when compared to national averages. The strength of these particular students had an impact on the results comparing the population that only took ME311, compared to the group that took both ME311 and ME312.

In Figure 4, the FEE results compared to national averages since 2006 are displayed for those programs that required both ME311 and ME312. In Figure 5, the same information

appears for those programs that only required ME311. The overall success rate of the latter programs is obviously much better. The contributors to that overall pass rate, while outside the scope of this paper, warrants further exploration in the future.

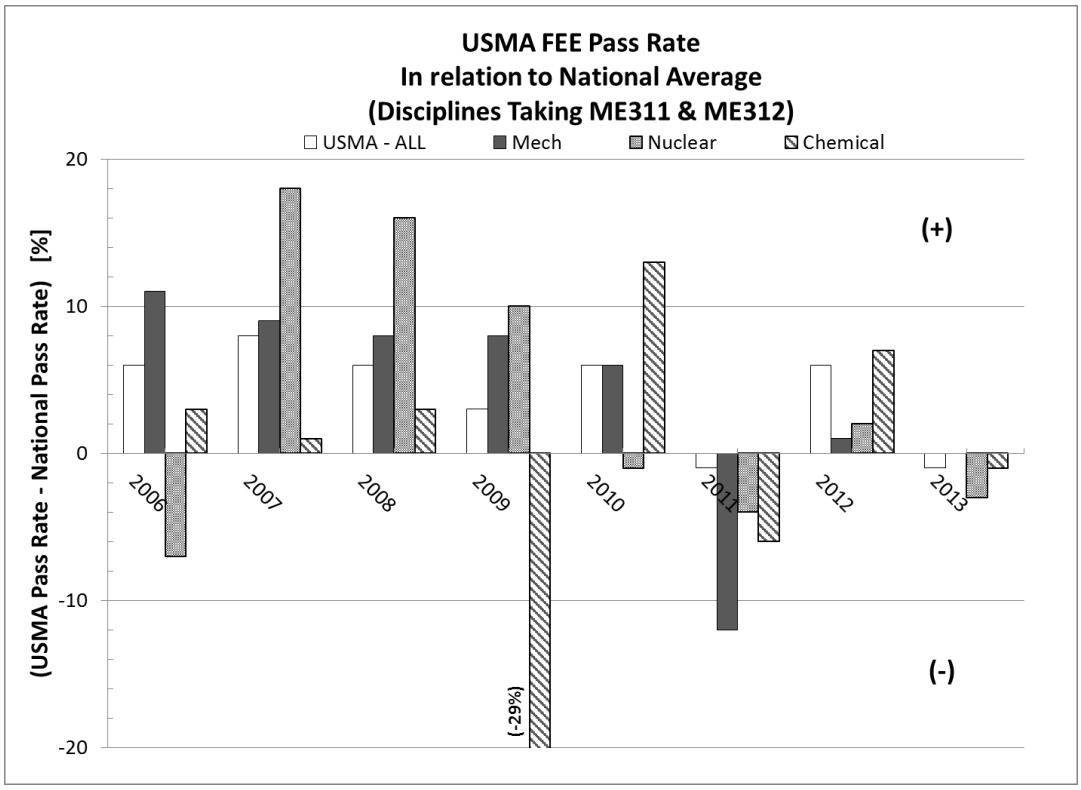

Figure 4: FEE Results Compared to National Average (post 2006, ME311 and ME312)

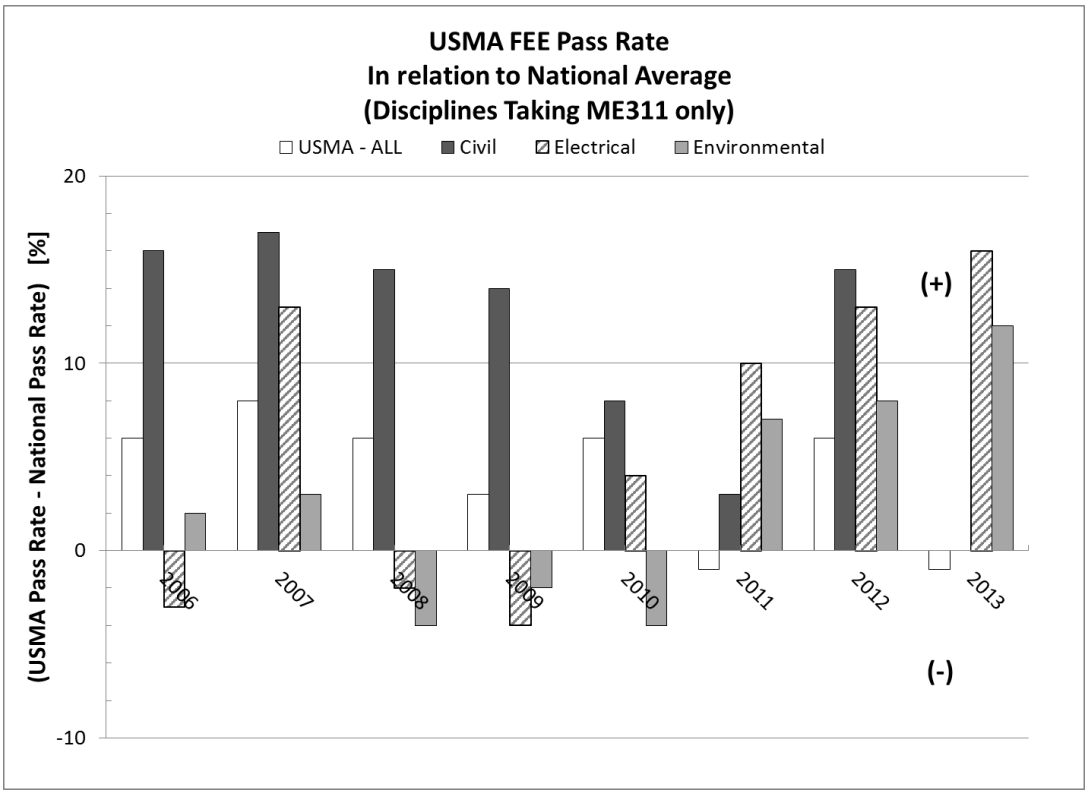

Figure 5: FEE Results Compared to National Average (post 2006, ME311 only)

Another conclusion of this paper, although not part of the original intent, is that the FEE is not the optimal indicator of the success of the courses in question. In particular, the fact that students taking two courses related to Thermal-Fluids did not have a significant benefit on related FEE topics compared to students only taking one course, demonstrates that additional assessment tools are required. The authors did attempt to compare other indicators both before and after the switch to the integrated sequence, unsuccessfully. Individual assignments throughout the course were not kept consistent enough to provide a meaningful basis of comparison. The one assessment tool that is kept very consistent from semester to semester is the final examination. However, a statistical examination of the final results prior to 2006 and after that date did not yield enough evidence to demonstrate a significant difference.

What is evident, is that the department requires a better tool to assess the efficacy of the integrated method of teaching these two important topics. While there are sufficient measures of performance that will be discussed below, there needs to be better measures of effectiveness, even if qualitative in nature to show whether students gain a better and deeper understanding of the relevant topics after the switch to an integrated course.

Conclusions and Summary

The decision to change the way the faculty presented these two critical engineering topics to students was not one taken lightly. The combination of external and internal drivers was enough to try the integrated approach that remains not widely accepted or implemented across engineering programs. The data indicates that this change had no negative impact on FEE results, and moderately positive results on questions related to Fluid Mechanics. There is some good news in these results for both the Mechanical Engineering program that implemented the changes, and for those outside the program.

For the programs that now only take ME311, the benefit is that they were able to gain space in their curriculum for an additional depth course in their program without any degradation in the ability to pass FEE questions related to the two topics in question. At an institution that requires a high number of humanities classes even for students in ABET engineering programs, gaining room for even one course is important. Students in West Point engineering programs typically take over 150 credits to obtain their BS degree.

For the programs that take ME311 and ME312, one benefit is the addition of topics that were not previously covered in Thermodynamics and Fluid Mechanics alone. Additionally, the faculty is able to cover some of the topics in ME312 in slightly more detail due to the efficiencies gained by teaching in an integrated manner. Again, this was one of the internal drivers for this change and it has worked.

What is often overlooked in this type of analysis are the benefits gained by not teaching something. The combined populations of the programs taking both ME311 and ME312 is approximately 100 students per class year. For those taking ME311 only, that number is roughly 70 per year. The latter equates to four classes at the Academy, since class sizes are limited to 18 students. Over the course of an academic year, the decision for several programs to take ME311 only, resulted in the reduction of four classes for the Mechanical Engineering faculty. That amounts to 160 hours of direct classroom instruction and at least twice that in preparation and grading for a minimum of 480 man-hours of time gained. Perhaps most important, is that the time gained did not come at the expense of results on Thermodynamics and Fluid Mechanics related questions on the FEE. The past decade has seen an increase in the number and complexity of Mechanical Engineering capstone projects requiring faculty advisors to spend additional time with their teams. It is likely that this increased time spent with the capstone projects would have not been possible without a corresponding decrease in time spent in teaching two courses to all of the engineering majors at the institution.

The largest disadvantage of the integrated approach to these two courses is in seeking equivalence at other institutions. Select cadets at USMA participate in exchange programs with the Naval and Air Force Academy every year. In addition, opportunity for study abroad has expanded as well. Almost all of these exchanges occur in a student's third academic year, which is when ME311 and ME312 are typically taken. Naval midshipman and Air Force cadets typically arrive already having taken Thermodynamics or Fluid Mechanics and then take Thermal-Fluids I at USMA, therefore repeating some material while not receiving the full benefit of the other material. Students from USMA who travel to other locations can often overcome this dilemma by taking ME311 as a distance student during their exchange experience.

At this time, the department is committed to continuing the practice of teaching these two topics in an integrated manner. In fact, the faculty already integrated Statics with Strengths of Materials and is exploring the possibility of integrating other topics such as Dynamics and Vibrations.

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[1] Daisie Boettner, Blace Albert, and Bret Van Poppel. "A Proposal For An Integrated Mechanical Engineering Curriculum At The United States Military Academy". 2003 Annual Conference, Nashville, Tennessee, 2003, June. ASEE Conferences, 2003. https://peer.asee.org/11426 Internet. 24 Sep, 2015

[2] Boettner, D. D., Norberg, S. A., Melnyk, R. V., Highley, J. L., Rounds, M. J., & Arnas, A. O. (2006, January). Teaching the Fundamentals of Thermodynamics and Fluid Mechanics through an Integrated Systems Approach. In *ASME 2006 International Mechanical Engineering Congress and Exposition* (pp. 81-89). American Society of Mechanical Engineers.

[3] Highley, Justin. "Lessons Learned From The Development Of a Follow-on Course In Thermal-Fluids Engineering." Spring 2006 Middle-Atlantic Section Conference. ASEE. http://www.asee.org/papers-and-publications/papers/section-proceedings/middle-atlantic/spring-2006

[4] Massachusetts Office of the Registrar, http://student.mit.edu/catalog/m2a.html. Date Accessed: 15 November, 2015.