AC 2007-941: ASSESSING A NEW THERMAL/FLUIDS SYSTEMS CURRICULUM USING FE RESULTS

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Assessing a New Thermal/Fluids Systems Curriculum Using FE Results

Abstract

As of the 2003-2004 academic year, the Department of Engineering Mechanics (DFEM) at the United States Air Force Academy assumed oversight of thermal/fluids systems courses required for its majors; these courses were previously managed by the Department of Aeronautical Engineering. As part of this shift, DFEM opted to transition to an integrated approach of thermodynamics, heat transfer and fluid mechanics, rather than teaching these topics individually. The new curriculum consists of 4 courses: the first 2 are required for Engineering Mechanics majors while Mechanical Engineering majors are required to take the first three courses, with the fourth course as an elective. While, this transition has been well received by students and faculty alike, however, DFEM sought a method to determine the efficacy of this transition; the Fundamentals of Engineering exam was a logical choice. Based on the results from three exams, preliminary results show that the transition did not detrimentally affect DFEM students' overall performance as they continued to pass the exam at or above the national average in each of DFEM's majors. However, upon inspection of individual subjects, there are a few areas in need of improvement. For example, DFEM majors have tended to score below the national average in thermodynamics on the morning portion of the exam. DFEM's thermal/fluids faculty has considered several items for improvement such as including more thermodynamic lectures in the required courses. Members of the DFEM faculty involved with the thermal/fluids curriculum will continue to monitor the FE results.

Introduction

Beginning in the of Fall 2003, the Department of Engineering Mechanics (DFEM) at the United States Air Force Academy (USAFA) assumed ownership of thermal/fluids systems engineering (TFSE) courses required of its majors. These courses include thermodynamics, fluid mechanics and heat transfer. As part of this change, DFEM decided to switch to an integrated approach to teaching these courses to provide continuity between these subjects. While this is new to USAFA, there are several other schools that have already implemented a similar approach, e.g. the Massachusetts Institute of Technology[1] and Rensselaer Polytechnic Institute[2]. The Fundamentals of Engineering (FE) exam seemed an appropriate metric upon which to base the efficacy of this new integrated approach to thermal/fluids engineering courses.

The first three courses share the same 3 blocks, which coincide with the 3 subject disciplines: thermodynamics, heat transfer and fluid mechanics. While beginning with an emphasis on thermodynamics, the fourth course deals primarily with different methods of energy conversion. Engineering Mechanics (EM) majors are required to take Thermal/Fluids Systems Engineering (TFSE) I and II, while Mechanical Engineering (ME) majors are required to take TFSE I-III; the fourth course, TFSE IV, is an elective for ME majors. Table 1 shows the goals and objectives for each course.

Table 1: TFSE Course Goals and Objectives

Course Goal / Objective	ME312 TFSE I	ME341 TFSE II	ME441 TFSE III	ME467 TFSE IV
Course Goal	Frame and resolve a variety of contemporary thermal fluids systems problems, with a concentration on the basics of mass, energy, and momentum conservation, conduction heat transfer, and entropy balance	Frame and resolve a variety of contemporary thermal fluids systems problems, with a concentration on applications to plant components, heat exchangers, and convection	Frame and resolve a variety of contemporary thermal fluids systems problems, with a concentration on the finite difference method, radiation, numerical methods, basic cycle analysis, psychrometrics, 1-D compressible flow, and turbomachinery	Analyze various conventional and novel means of converting energy into useful forms
1	Effectively communicate results of engineering analysis, testing, and design, both individually and as a member of a team	Effectively communicate results of engineering analysis, testing, and design, both individually and as a member of a team	Effectively communicate results of engineering analysis, testing, and design, both individually and as a member of a team	Effectively communicate results of engineering analysis, testing, and design, both individually and as a member of a team
2	Understand and apply the 1st and 2nd laws of thermodynamics, and the basic modes of heat and work interaction (emphasis on conduction)	Understand the concept of isentropic processes and apply it to plant component efficiency calculations	Identify numerical methods appropriate for the analysis of various heat transfer and fluid flow problems.	Understand and apply efficiency improvements to basic power, refrigeration/heat pump, and combined cycles
3	Understand the significance of Carnot cycle as the ideal against which others are measured; understand COP for refrigeration/heat pump cycles	Understand and apply dimensional analysis and the Buckingham Pi theorem, with particular emphasis on modeling and similitude	Understand and analyze basic power cycles (Rankine, Otto, Diesel, Brayton, etc.)	Understand and apply the fundamental aspects of combustion, with emphasis on the energy transfers involved
4	Perform basic fluid mechanics calculations associated with fluid statics, the Bernoulli and mechanical energy equations, and conservation of linear momentum	Analyze basic plant devices (turbines, pumps, compressors, etc.) and cycles	Understand and analyze various turbomachinery components, including appropriate velocity diagrams	Identify miscellaneous means of energy conversion (solar, wind, fuel cells, etc.), their benefits and drawbacks, and how to integrate them into energy conversion systems
5	Understand the electrical analogy to heat transfer, with specific application to conduction	Understand and apply the convection heat transfer phenomenon, with particular emphasis on shell and tube heat exchangers	Understand and analyze systems comprised of non-reacting substances and their applicability to psychrometric processes	
6		Understand the derivation of the Navier-Stokes equations and how they may be simplified to analyze different flow situations	Understand and analyze systems involving 1-D compressible flow and normal shocks	
7			Understand and apply the radiation heat transfer phenomenon.	

Table 1 suggests that EM majors do not receive instruction in radiation heat transfer. On the contrary, during TFSE I, EM majors are exposed to basic radiation heat transfer in sufficient detail for the FE exam.

Results and Discussion

Table 2 shows the exam statistics for DFEM students who took the FE exam. Notice that the data are broken down by major, afternoon exam selection, the number passing based on afternoon exam selection and the number of students nationally in each major who took the exam based upon afternoon exam selection.

Table 2: DFEM and National FE Exam Statistics, 2001-2006

	EM			ME		
	Gen PM/Mech PM	Pass	Nat'l	Gen PM/Mech PM	Pass	Nat'l
2001	10/0	10/0	76/0	17/0	16/0	1991/0
2002	17/2	15/1	76/13	20/0	19/0	2430/0
2003	28/1	28/1	100/9	32/0	31/0	2766/0
2004	18/6	16/6	87/30	38/5	31/4	2684/1145
2005	10/6	8/5	78/21	14/12	13/9	2721/1287
2006	8/0	7/0	68/0	11/3	11/1	2747/1479

DFEM does not require its students to take the FE exam. Accordingly, one will notice a large spread in the number of students who took the exam. For instance, approximately one-third of DFEM majors took the FE exam in 2006 compared to the total number that took the exam in 2003 despite no significant reduction in the number of majors during the same time period.

Figure 1 shows DFEM's normalized results for the morning portion of the exam for 2001-2006. While the data show that DFEM's majors have consistently scored close to the national average, they indicate a significant difference between EM and ME scores following the TFSE integration. Recall that beginning with the 2005 scores, DFEM majors were exposed solely to the new curriculum. Therefore, it is reasonable to expect a difference between EM and ME scores due to the number of TFSE courses required of each major, with ME students likely scoring higher due to the third required course and the fourth elective course. Additionally, a comparison to the national average is not appropriate, given that EM majors comprise a large fraction of EM majors nationwide compared to a similar ratio for ME majors (see Table 2). As such, all remaining data will focus solely on DFEM data.

However, the morning portion of the exam does not provide the complete picture. The afternoon portion, with its more in-depth material, should provide additional information.

The National Council of Examiners for Engineering and Surveying, NCEES, changed the afternoon FE exam topics in October 2005. As such, a direct comparison of the pre- and post-integration afternoon results, either General or Mechanical, is difficult. However, the following data give some information related to the efficacy of the transition to the integrated curriculum.

Figure 2 shows the average percent correct for DFEM majors who took the General PM exam for 2001-2005, while Figure 3 shows similar data for 2006.

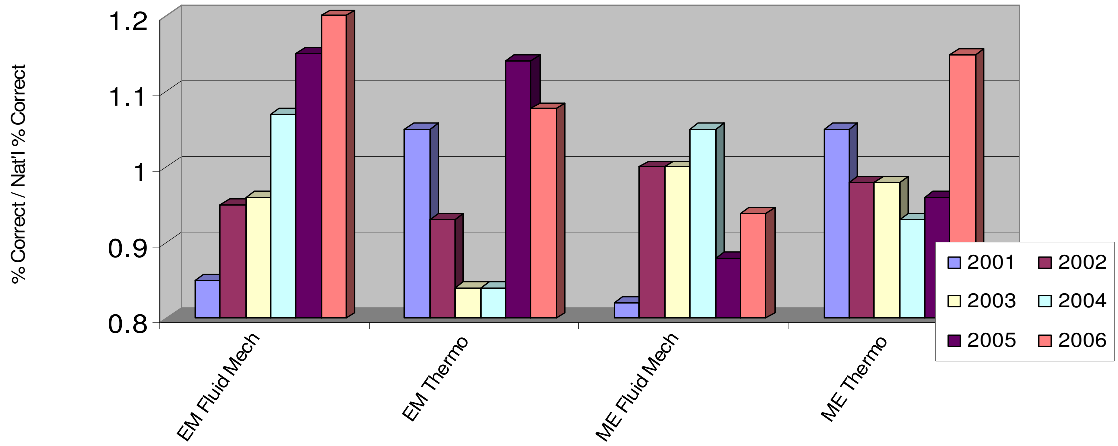

Figure 1: TFSE Subjects on AM Test; Comparison to National Results

Upon closer inspection of Figure 2, one will notice that prior to the integrated curriculum (2001-2003) EM and ME majors tended (within 6-7%) to receive the same score on both the TFSE topics of the General PM exam. Following the integration (2004-2005), ME majors tended to outscore EM majors by a larger margin, approximately 10%. This is a reasonable trend due to the required courses in each major. However, this trend is not consistently exhibited in the data of Figure 3.

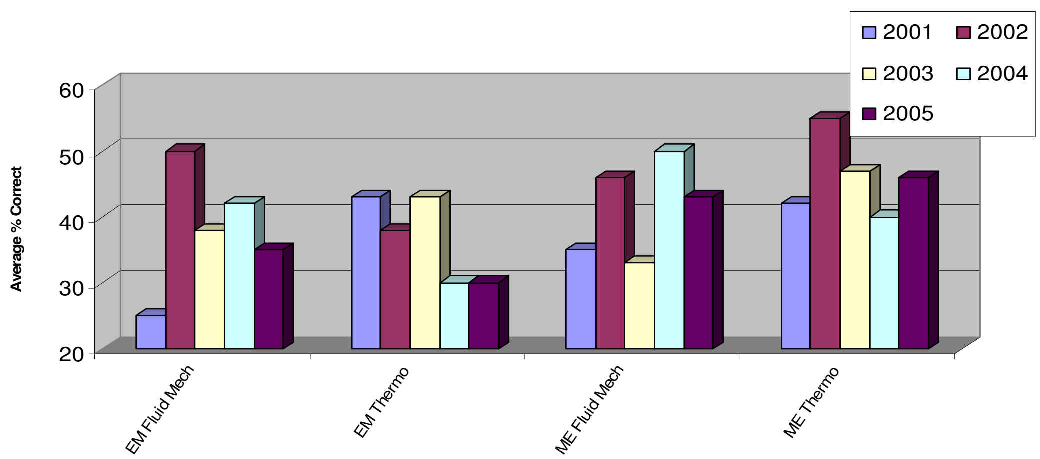

Figure 2: TFSE Subjects on General PM Test; DFEM Only, 2001-2005

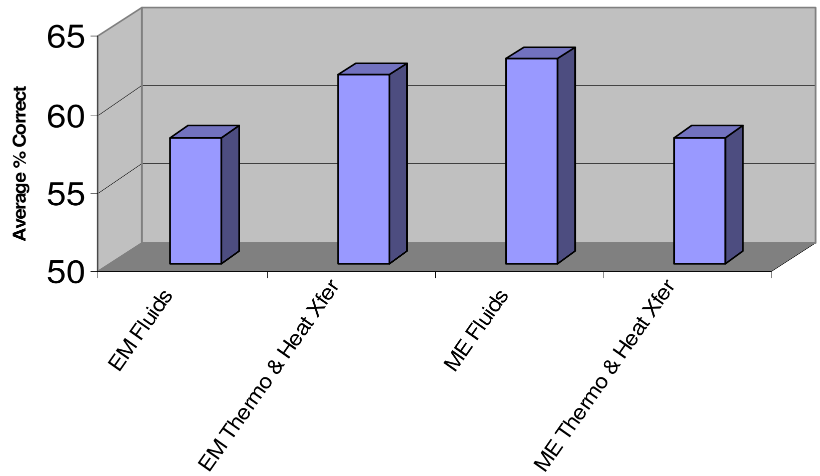

Figure 3: TFSE Subjects on General PM Test; DFEM Only, 2006

The data shown in Figure 3 are mixed, with MEs outscoring EMs in Fluids but not in Thermodynamics and Heat Transfer. A comparison of means statistical analysis was performed on EM and ME grade point averages (GPAs) to determine if it would provide some insight into the difference. Table 3 shows the results of that analysis, where t_α represents the Student t value at the 95% confidence level:

$$t = \frac{\left|\bar{x}_2 - \bar{x}_1\right|}{\sqrt{\frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}\left(\frac{n_1 + n_2}{n_1 n_2}\right)}}$$

As one will notice, the means were not statistically different ($t < t_\alpha$) for any year examined. Therefore, the difference in EM and ME FE results is not likely due to a difference in major and cumulative academic performance. However, the difference could be due to performance in TFSE courses. This will be discussed further in the Recommendations section.

Data for the Mechanical PM exam are more difficult to compare and contrast due to the fact that no MEs took this exam (2001-2003) prior to the integration 2003/2004. However, as shown in Figures 4 and 5, following the integration MEs consistently outscored EMs in topics to which EMs were not directly exposed. These topics include Energy Conversion (TFSE IV), Fans, Pumps and Compressors (TFSE III) and Refrigeration and HVAC (TFSE III/IV).

One disturbing trend shown in the afternoon exam results (see Figures 2, 4 and 5), although the statistical significance might not give the complete picture, is that the scores tended to decline from 2004 to 2005. This trend is not shown in the morning exam results (see Figure 1). While this downward trend may show a flaw in the integrated curriculum, the 2006 results in Figure 3 show an increase in Thermodynamics and Heat Transfer scores. Although this is not a direct comparison of topics (Figure 2 shows only Thermodynamics), it gives some confidence that the integrated approach is not solely to blame. Additionally, the decrease in Energy Conversion from 2004 to 2005 is partially explained by a decrease in TFSE IV enrollment in TFSE IV, with 15 students in 2004 and 8 students in 2005.

Table 3: Comparison of GPA Statistics

	EM CUM GPA			ME CUM GPA				
	n	$\bar{x}$	S	n	$\bar{x}$	S	t	t_α
2001	16	3.16	0.36	25	3.13	0.37	0.19	2.02
2002	33	2.98	0.32	34	3.01	0.45	0.33	2.00
2003	41	3.10	0.37	50	3.03	0.36	0.82	1.99
2004	29	3.05	0.35	59	3.13	0.46	0.85	1.99
2005	22	3.14	0.37	31	3.11	0.46	0.24	2.01
2006	11	3.14	0.46	26	3.25	0.36	0.79	2.03

	EM MAJ GPA			ME MAJ GPA				
	n	$\bar{x}$	S	n	$\bar{x}$	S	t	t_α
2001	16	3.24	0.35	25	3.20	0.47	0.30	2.02
2002	33	2.97	0.36	34	2.98	0.52	0.09	2.00
2003	41	3.03	0.43	50	3.01	0.42	0.22	1.99
2004	29	3.07	0.43	59	3.16	0.52	0.79	1.99
2005	22	3.12	0.42	31	3.12	0.49	0.00	2.01
2006	11	3.13	0.56	26	3.19	0.50	0.34	2.03

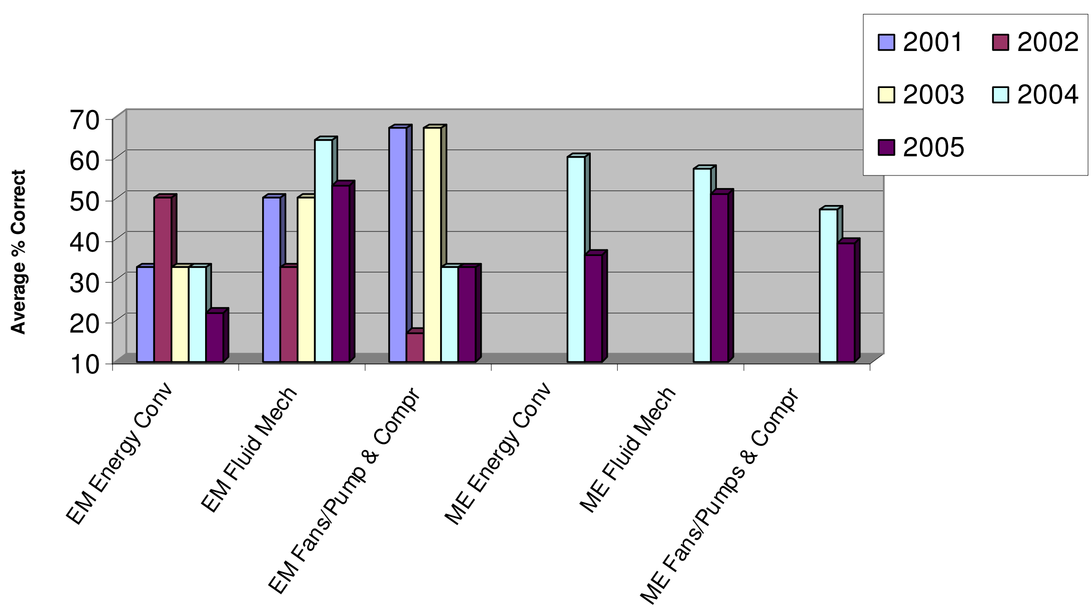

Figure 4: TFSE Subjects on Mechanical PM Test; DFEM Only, 2001-2005

Figure 5 does not include data for 2001 as no DFEM students took the Mechanical PM exam that year. Additionally, this figure also shows that EMs received zero percent correct in 2003 on the Refrigeration and HVAC topic and the same score in 2002 on the Thermodynamics topic.

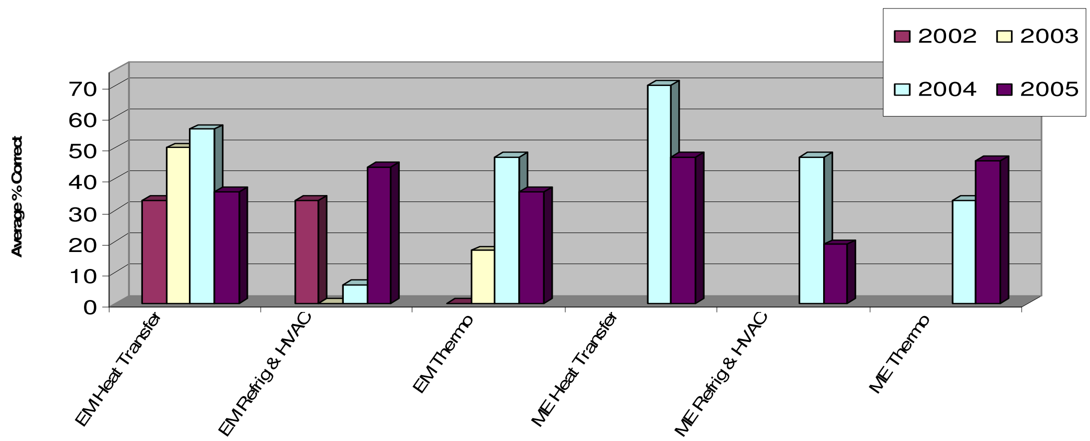

Figure 5: TFSE Subjects on Mechanical PM Test; DFEM Only, 2002-2005

Figure 6 shows the results for the Mechanical PM exam for DFEM only for 2006. Notice that the TFSE topics are different from those shown in Figures 4 and 5. This is again due to the NCEES change in afternoon exam topics in October 2005. When one considers this topic change, and since there are few data, an in-depth discussion is not possible. However, one topic that did not change is Refrigeration and HVAC. In comparing Figures 5 and 6, one will notice a significant decline in the average percent correct in this topic. One reason for this is the small sample size for 2006 (see Table 2). Another reason is likely due to the need for an additional metric to compare students in each major (see the Recommendations section).

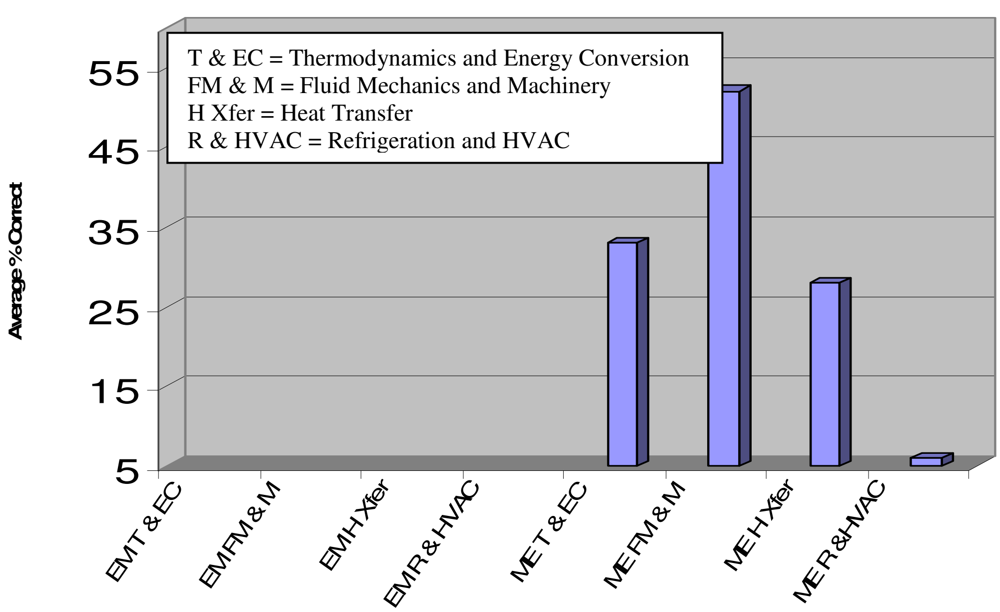

Figure 6: TFSE Subjects on Mechanical PM Test; DFEM Only, 2006

In viewing Figure 6, one will notice that there are no EM data because all EMs took the General PM exam.

In addition to these FE exam data, it is relevant to examine student feedback to the TFSE integration. In Spring 2004, the students enrolled in TFSE II responded that 63% were in favor of the new, integrated curriculum when compared to the conventional curriculum of 3 separate courses. This is an important result since approximately one-fourth of these students had experienced both curricula. Additionally, graduating students from that same semester responded that they liked the integrated text and thought that experiencing similar material over multiple semesters improved their retention of the material.

Conclusions

The present work examined the FE exam results from 2001 to 2006 in an attempt to determine the efficacy of a new integrated thermal/fluid systems engineering curriculum at the United States Air Force Academy's Department of Engineering Mechanics.

The comparison of USAFA's scores to national averages is a bit misleading due to a small sample size. For instance, in 2005, USAFA accounted for nearly 16% of all Engineering Mechanics majors nationwide who took the exam, while accounting for only 0.6% of all Mechanical Engineering majors nationwide who took the exam. Given this disparity, the authors believe that the best comparison is between majors and the average percent correct for each portion of the exam: morning, General PM and Mechanical PM.

The FE exam results show that there has not been a detrimental change following the curriculum integration: there has been no significant decrease in student performance. Additionally, and generally speaking, MEs have outscored EMs in TFSE-related topics. This trend is likely due to the requirement for MEs to take the third course, which then allows them to take the fourth course as an elective. However, there are some instances where this did not occur and DFEM's faculty will continue to monitor this trend. A comparison of means statistical analysis was performed on EM and ME major and cumulative GPAs, which showed that the means were not statistically different. This indicated that an additional metric is likely needed to explain this difference between EM and ME FE performance in TFSE topics.

Recommendations

While the FE exam provides a standard upon which to base the TFSE integration, the authors feel that an additional metric is required to better assess the knowledge and retention between classes of students. Specifically, the authors will continue to examine major and cumulative GPAs, but will also include GPAs for TFSE courses for its future classes of EM and ME majors.

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[1] http://student.mit.edu/catalog/m2a.html accessed Feb 21, 2007
[2] http://www.rpi.edu/academics/catalog/pdf06-07/RPI_Catalog_0607.pdf accessed Feb 21, 2007