

## **An Integrated Thermal and Fluids Curriculum**

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### Abstract

This paper presents the efforts made in our department in implementing an integrated Mechanical Engineering core curriculum, in particular, our first-year experience in the teaching of the integrated thermal and fluids courses. In the traditional curriculum, the study of thermal sciences is categorized into three major subject areas: thermodynamics, heat transfer and fluid mechanics, where they are usually taught as separate entities over three or more semesters. This approach is pedagogically convenient but not necessarily effective since it creates the false impression among the students that the analysis of a thermal system is simply a combination of several loosely related disciplines. The newly designed thermal course-sequence is designed to correct this deficiency by integrating these subjects into a single two-semester course sequence to provide students with a coherent understanding of a complete thermal system. A parallel effort is also underway to combine the traditional thermal and fluid laboratory course into the integrated thermal course. In addition to the emphasis on the introduction of experimental techniques, data analysis methods and enhancement of oral and written communication skills, the new laboratory course will be taught at the same time with the thermal fluids course thus providing the “just-in-time” hands-on experience for students. In summary, our endeavor experience with this wholesale curriculum renovation, including difficulties encountered and suggestions for future improvements, will be discussed in detail.

### 1. Introduction

As we are entering the 21<sup>st</sup> century, the traditional methodology for teaching engineering is being scrutinized as to whether it can effectively produce competent engineers who can handle the many challenges brought upon by the multiplying, interrelated-technologies and global competition. It is generally agreed that in the future engineers need to have a comprehensive knowledge base to tackle complex, multidisciplinary assignments. Unfortunately, the current engineering education has often failed in this aspect and that is why the National Science Foundation (NSF) has cooperated with several universities<sup>1</sup> to establish pilot programs to devise plans to implement a wholesale renovation of the engineering education.

Among many concepts, NSF has identified “Engineering Curriculum Integration” as one of the most promising innovations<sup>2,3</sup>. It is proposed that new engineering curricula should teach the connectivity of relevant engineering subjects and emphasize their relationship to practical engineering processes. Positive results from schools experimenting with the integrated curricula,

especially when combined with other instructional technology methods, confirm that this is the proper direction for the engineering education. Not by coincidence, the Accreditation Board for Engineering and Technology (ABET) also recently announced its new “Engineering Criteria 2000”<sup>4</sup>, emphasizing curriculum integration, as the accreditation standard for all U.S. engineering programs after year 2001. It is clear that a paradigm shift in how we teach our students is forthcoming and any further delay will result in the production of under-prepared engineering graduates of the future. Based on these concerns, in 1996 a workshop<sup>5</sup> for U.S. Mechanical Engineering Departments was organized to discuss these various issues and many recommendations were made, especially in terms of the wholesale curriculum integration.

Based on many of the suggestions proposed at the MIT workshop, several faculty meetings were initiated in the Department of Mechanical Engineering at the FAMU-FSU College of Engineering to discuss the need for a paradigm shift and the faculty reached a unanimous conclusion: “we must make wholesale changes in our curriculum now.” The integrated ME curriculum, briefly described below, has just completed its second year of implementation. In this paper, we are presenting our experience in implementing this new curriculum with an emphasis placed on the Thermal and Fluids courses sequence.

## 2. FAMU-FSU College of Engineering and Mechanical Engineering Department

The FAMU/FSU College of Engineering has been a unique institution since its inception in 1982. It is jointly sponsored by Florida A&M University, a historically black university, and Florida State University. The College embraces the mission statements of both Universities and hence strives to provide greater minority and women participation in both undergraduate and graduate engineering education while achieving national and international recognition of the College through the educational and research achievements and the professional service of its faculty and students. The Department of Mechanical Engineering has an enrollment of 335 undergraduate students of which 63% are underrepresented minorities and 18% are female. The diverse population of our school makes the transition to the new curriculum both more challenging and necessary and since it can provide motivation to our students and, hopefully, achieve our goal to improve the retention rate.

## 3. The Integrated ME Curriculum

With the aforementioned objectives of developing a curriculum that emphasizes the relationships between mechanical engineering topics, the existing mechanical engineering curriculum was carefully reexamined by all faculty members. We especially focused on reorganizing the curriculum to develop a coherent presentation of this interdisciplinary information to our students. The ultimate goal of the new curriculum was to emphasize the inherent connectivity of the disciplines used in engineering practice in addition to teaching the fundamental principles of mechanical engineering. With this in mind, representatives from four sub-groups, thermal sciences & fluids, mechanics & materials, dynamics & controls, and mechanical design met separately to formulate the new integrated ME curricula. Based on a pilot models implemented earlier in other ME departments (for examples, at the Massachusetts Institute of Technology) we consolidated the twelve traditional, discipline-specific 3 credit courses into a set of four, two-course sequences consisting of 4 credit hour courses. In particular, (1) *Thermal Fluids I & II*

integrate the traditional thermal and fluid science subjects of *Thermodynamics, Heat Transfer and Fluid Mechanics*, (2) *Mechanics and Materials I & II* integrate *Statics, Mechanics of Materials* and *Materials Engineering*, (3) *Mechanical Systems I & II* replace *Mechanism Design, Design of Machine Elements* and *Computer-Aided Design & Manufacturing*, and finally (4) *Dynamic Systems I & II* combine *Dynamics, Mechanical Vibrations* and *Control Theory*. These courses are required core courses for all mechanical engineering majors during their sophomore and junior years. These classes will be offered every semester in consecutive sequence. The Thermal and Fluids I & II course sequence will be discussed in details later.

### 3.1 Vertical Integration

Our new program is also restructured such that it is integrated vertically throughout the entire curriculum. Several key integration concepts are adopted as follows: (1) provide students with general skills required for their engineering problem solving as early as possible; (2) reinforce these skills continuously throughout the curriculum; (3) offer more technical elective courses for students to choose during senior year; (4) strengthen the senior capstone design project which utilizes and integrates the skills learned in the integrated curriculum and requires the creation of a final product, similar to an industrial engineering process. To achieve these goals, two new courses were introduced during the sophomore year: (1) *Introduction to Mechanical Engineering* provides an overview of the engineering profession, design process and communication skills; (2) *ME Tools* equips students with computer skills and machining tools necessary for their subsequent Mechanical Engineering courses. In combination, these two courses provide students with a good first hand experience of applying their knowledge in mathematics and physics to the engineering problem solving. On the other hand, they also learn the engineering design process at an early stage. Another important element to ensure the success of the new curriculum is that these skills have to be applied repeatedly throughout the students' education. For example, all core courses are required to use the MathCAD® and Matlab® packages for computational purposes in their classes. Microsoft Excel and Word are used for students' spreadsheet and written reports, while PowerPoint is required for all presentations. Other design tools such as ProEngineering® and ALGOR® FEM package are also integrated throughout the entire curriculum.

### 3.2 Technical Electives and Senior Design

To complete the integration, technical electives and capstone design courses are also revised. The required technical electives are increased from two to four to provide the flexibility to our senior students so that they can either diversify their educational background or focus their interest in a specific discipline. In addition, the design course is changed from the old one-semester course to the current two-semester format. The new class covers all aspects of engineering design, including problem formulation, conceptualization, design planning, optimization, reporting and implementation, etc. The class emphasizes “In-Practice” learning by going through the entire design cycle on specific projects. A team-based project is assigned to a group of students at the beginning of the first semester. A complete hands-on implementation of the design process will be achieved at the second semester. It is our belief that through this two-semester design program, students can finally integrate their engineering knowledge, skills and creativity gained throughout the years into the realization of a final design product.

#### 4. The Integrated Thermal and Fluids Courses

Traditionally, the thermal sciences have been categorized into three major subject areas: Thermodynamic, Heat Transfer and Fluid Mechanics, where they are usually taught as separate entities over three or more semesters. However, this sequential education process teaches discipline-specific component engineering rather than systems engineering. It leads to the misconception that an engineering education is simply the completion of a collection of courses. Therefore, we designed this new thermal course-sequence with the aim of correcting this deficiency. The new two-semester course sequence, Thermal Fluids I & II, replaces the four core thermal science courses: Thermodynamics, Applied Thermodynamics, Heat transfer and Fluid mechanics. The Thermal and Fluids I & II sequence was taught for the first time in the 1998, fall semester. The weekly schedule of this new class includes three one-hour lectures plus one three-hour workshop session. Case studies based on real-world thermal systems are used throughout the class to illustrate the relationship and connectivity between these interdisciplinary subjects. Modeled after the “just-in-time” delivery concept, new subjects are introduced based on their relevancy to the thermal systems being analyzed. For example, a solar power plant is the first case study introduced; its design consideration includes different modes of heat transfer, fluid mechanics issues such as pipe flow network, and thermodynamics power cycle analysis. Many of these thermal systems are used throughout the courses in order to provide students with a comprehensive understanding of a complete thermal system.

The course sequence begins with an overview of all three major disciplines: heat transfer, fluid mechanics and thermodynamics, in that order. One of the common themes to link all these subjects is the conservation principle: from the first law of thermodynamics to the heat diffusion equation in heat conduction mode and to the extended Bernoulli's equation used to describe the mechanical energy in a fluid system. Other concepts that can be logically integrated include fluid mechanics and forced convection heat transfer for both internal and external flows, entropy generation due to heat transfer and viscous dissipation, to name a few. However, special care was taken not to combine subjects just for the sake of integration since many fundamental principles sometimes are better presented separately or should follow a particular sequence. Another important lesson that we learned in the implementation of the new curricula is to *prioritize* the instructional materials to ensure that important subjects are not left out in the process of integration.

##### 4.1 Cooperative learning

Cooperative learning was also introduced, implemented and reinforced by assigning students into groups working together for homework and workshop assignments. The effective use of the three-hour workshop period is found to be extremely important in the success of the new curriculum. It is well known that teaching in a regular lecture setting, i.e. the “sage on stage model”, is not always effective. It is almost impossible to teach complex subjects only through verbal presentation with limited interaction between students and the instructor. Consequently, “just-in-time” assignments on key and/or complicated concepts were given during the workshop period to reinforce these areas. Based on our experience to date, extended discussion on these difficult-to-comprehend concepts in a cooperative environment appears to be an effective tool for

students to acquire a better understanding of the subject materials. In addition, direct interaction in a group encouraged the development of interpersonal skills and built positive relationships among students thus promoting the development of a true learning community.

#### 4.2 Textbook and web-based supplements

At the present time, there are no textbooks available that cover all these three subjects in a coherent manner. Consequently, two different texts are assigned: *Introduction to Thermodynamics and Heat Transfer* by Y. Cengel and *Introduction to Fluid Mechanics* by Fox and McDonald. However, to achieve full integration supplementary materials had to be provided by the instructor in order to ensure smooth transitions between different disciplines.

Furthermore, constant introduction of real-world applications and hands-on demonstrations are also critical to the success of the integrated courses. Therefore, an effort was made in the past few semesters to establish comprehensive course web pages that can serve dual functions: both as a teaching tool to assist lecture delivery and as a ROAD MAP to guide students in these new courses. These pages can be found at the following addresses:

<http://www.eng.fsu.edu/~shih/eml3015/thermal-fluid.htm> and

<http://www.eng.fsu.edu/~shih/eml3016/thermal-fluid.htm>. There are three major sections in these pages: (1) Course organization section contains the usual course supplements such as the course syllabus, homework assignments & solutions, test solutions, etc. (2) Lecture materials section includes daily lecture notes and weekly workshop assignments. (3) Finally, a guidance section is prepared to provide a ROAD MAP to guide students through different subjects in the class. Each thermal-fluid related topic is discussed in one web page with the help of many hyperlinks to relevant references on the web. An additional *Web Pages of the Week* section is also included to link to web pages that introduce students to beyond-the-textbook experience of subject matters discussed during that week. Two of these supplements, *Quantitative Flow Visualization* and *A Hypermedia Road Map for the Teaching of Thermal and Fluids courses*, have been submitted to the Southern University and College Coalition for Engineering Education (SUCCEED) and was included in the CD-ROM Greatest Bits Vol. 2 CD 1999<sup>6</sup> and Vol. 3 CD 2000<sup>7</sup>, respectively.

In the weekly three-hour workshop period, mini-projects are assigned where the students are required to first model the problems using thermal principles learned in the classroom. This is then followed by numerical solutions of simple design problems involving the theory using engineering software packages. However, a critical deficiency in the current workshop format is that there is not sufficient hands-on experience and interaction, other than computer usage and limited in-class demonstration. Therefore, the enhancement of laboratory experience by integrating the class with the thermal and fluids laboratory is identified as a priority for the improvement of the new courses.

#### 4.3 Laboratory Integration

No matter how sophisticated demonstration/computational packages maybe, they cannot replace real hands-on laboratory experience. Therefore, we are currently integrating the thermal and fluids laboratory course with the integrated thermal fluids course sequence. The laboratory course used to be taught after the completion of the thermal core courses and placed an emphasis

on the introduction of experimental techniques, instrumentation, report writing and to reinforce students' understanding of thermal-related subjects. In the new format, the laboratory course will be taught at the same time with the thermal fluids II course and provide the "just-in-time" hands-on experience for students. The laboratory sequence will be arranged to follow as closely as possible the teaching progress in the integrated thermal class. The total integrated learning concept begins by first presenting fundamental principles from a system approach, followed by demonstrations of how these theories can be applied to practical applications and finally, providing students with hands-on laboratory experience.

Over the past year, we have converted all traditional thermal and fluids laboratory manuals into an on-line format and made them available to all students over the web at the course web page (<http://www.eng.fsu.edu/~alvi/EML4304L/webpage/>). The extensive course web page for the lab also allows us to emphasize the connectivity between the laboratory course and the concepts learned in Thermal Fluids I and II by providing dynamic links to the relevant sections on the Thermal Fluids I & II web pages. Currently, we are moving a step further to transform these on-line manuals into a **VIRTUAL LABORATORY** environment. These virtual experiments are highly interactive and enhanced by visualization and animated demonstrations using imaging processing technology. We require students to browse through this web-based laboratory and perform these virtual experiments before they actually walk into the real laboratory. Therefore, the real experiments can be operated more effectively and make for a richer learning experience. These virtual experiments are all visualization-enhanced and can be used to assist the regular classroom teaching. They will be presented as fully interactive web pages that emphasize the "seeing is believing" concept to stimulate students' learning interest. These pages will be integrated into the course web pages to provide relevant discussion about the interrelationship between the practical applications and the fundamental principles. For example: a virtual experiment of wake measurement behind a sphere can be linked to the discussion of aerodynamics of a golf ball, and drag force on an aircraft in the **ROAD MAP** pages. The measured momentum deficit and wake profiles in the laboratory pages can be related to the theory of conservation of linear momentum. Similarly, temperature distribution of an extended fin in the laboratory can be used to supplement the discussion of enhanced heat transfer in a CPU chip presented in the **ROAD MAP** pages. We believe that the integration of these virtual laboratory results with the unlimited reference resources available over the web will undoubtedly enhance students' understanding and, at the same time, stimulate their interests in learning the thermal and fluid sciences.

## 5. Final Remarks

There are many obstacles in designing an integrated curriculum. The most critical one probably is to obtain a consensus among the faculty members and convincing them that the additional effort, which is considerable, is worthwhile. In our situation, this is not a problem since most of the faculty members generally agree that a change is necessary. However, obtaining consensus regarding the details of how and who will develop the new curriculum is not an easy matter. In general, faculty do not like the added demands of developing and teaching the new classes since usually there are no rewards or recognition for such efforts. Moreover, their extra efforts might receive criticism if they do not conform to others' expectations. However, these concerns can be

resolved as long as the assigned teacher(s) understand the program's philosophy and has the patience, enthusiasm and flexibility to implement the necessary innovations.

Students' resistance to change might be more difficult to deal with since they usually resent for having to do more work. It is even harder to try to convince the first group of students that the integrated program is beneficial to their education. This is especially true at the beginning of a new program when, by necessity, things are sometimes not as well organized as one would like them to be. Unrealistic expectations from the instructors plus poor coordination among classes can overburden students and discourage their willingness to participation. The success of the entire program can be undermined if a majority of the students have a negative view about an experimental program. To rectify these concerns, frequent and effective communication with the students is essential.

The feedbacks and suggestions from students and other faculty members are important since the development of an experimental program is an iterative process. There should be no illusion that our program is going to work perfectly for the first time. As a matter of fact, we have discovered many shortcomings and oversights and have implemented, and continue to implement, several significant corrections and changes to this curriculum.

Teamwork and cooperative learning concepts are implemented throughout the curriculum. The emphasis on team concept is more important in an integrated curriculum as compared to a traditional one. The subject areas are more involved with several interrelated disciplines where the students more frequently encounter open-ended questions. Students working in a group environment should achieve a better understanding because their comprehension of different subjects is usually complementary.

From our personal point of view, teaching these familiar subjects using an integrated approach poses a refreshing challenge since we had no prior experience in either learning or teaching this way. This change forces us to abandon some cherished though out-of-date practices and allows us to dissect these familiar topics with a new perspective. At the very least, we have to create a new set of lecture notes to accommodate all these new aspects into our teaching. We have to admit that, without this wholesale change, we probably will be hesitant to make any monumental modifications. In addition, this also accelerates our utilization of instructional technology by teaching and providing guidance through web extensively.

## 6. Summary

Our efforts in implementing an integrated Mechanical Engineering core curriculum are discussed in this paper. All core Mechanical Engineering courses are redesigned and integrated vertically throughout the curriculum. In particular, the newly-designed thermal course-sequence is designed to combine three separated thermal disciplines, thermodynamics, heat transfer and fluid mechanics, into one two-semester course sequence to provide students with a coherent understanding of a complete thermal system. A parallel effort is also underway to combine the traditional thermal and fluid laboratory course into the integrated thermal course. In addition to the emphasis on the introduction of experimental technology, enhancement of oral and written communication skills, the new laboratory course will be taught at the same time with the thermal

fluids course and provide the “just-in-time” hands-on experience for students. In summary, we believe that several key factors such as faculty commitment, student participation, cooperative learning and careful planning and iterative corrective process are essential to the success of the program.

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