Implementation of an On Line Course on Heat Transfer and Fluid Mechanics

Francis A. Kulacki, ASME Fellow
Professor
Department of Mechanical Engineering
University of Minnesota- Twin Cities
Minneapolis, MN 55455
kulacki@me.umn.edu

Hitoshi Sakamoto, ASME Member
Graduate Teaching Assistant
Department of Mechanical Engineering
University of Minnesota- Twin Cities
Minneapolis, MN 55455
hsakamot@me.umn.edu

Jeanne L. Swope, Media Program
Project Developer
College of Continuing Education
University of Minnesota- Twin Cities
Minneapolis, MN 55455
swope002@umn.edu

The conceptual and pedagogical frameworks of an on line course in heat transfer and fluid mechanics are presented, and the developmental process, modular course structure, and production process are described. The goal is to provide a glimpse into the process of bringing one form of on line education to an operational level at a time when the Internet and its related technologies seem poised to pervasively impact engineering education. The underlying motivation for developing the course is the realization that content and instructional methods in key subjects of the mechanical engineering curriculum have not changed all that much for past 30 years. Thus, heat transfer and fluid mechanics, at least at the introductory level, represent mature subjects for which teaching them can be transformed by digital and communications technologies. The on line course described here can be accessed either at www.me.umn.edu/courses/me3322/ or via a CD-ROM available from the senior author.

INTRODUCTION

Over the past 30 years, teaching techniques and delivery modalities in mechanical engineering have not really changed much, and the educational process has not yet universally embraced computer-based and Internet-based methods. Undergraduate and master's level instruction today mainly comprises a series of print based courses wherein instructors essentially lead the students through more or less standard treatments of engineering topics. Moreover, a review of several competing texts in thermodynamics, heat transfer, and fluid mechanics shows little if any differences in content and presentation, at least at the introductory and intermediate levels. Additionally, their respective contents are not much different from that of the texts used a generation ago.

Moreover, course development yet tends to be done in the traditional manner: A set of notes is written based on an individual's knowledge of the subject and the presentation of the subject in the text selected for the course. The course notes are then used as a script in the classroom setting. After the initial development of the course notes and one or two presentations of the course, the notes and the course content remain essentially unchanged. Local teaching customs and how courses are delivered at a particular institution influence an individual's teaching style and to some extent pedagogy. Nevertheless, the pedagogy observed today remains largely teacher-centered, much the same as it was a generation ago, and it appears that most engineering schools yet adhere to traditional and comfortable teaching and learning paradigms that promote a passive kind of learning. Students too seem to be accustomed to a passive role by the time they begin their critical core courses in mechanical engineering

From the administrative viewpoint, the productivity of the teaching process has hit a plateau, and traditional methods of teaching limit faculty productivity and teaching effectiveness in the face of a greatly expanded knowledge base for mechanical engineering. The result is that the cost basis of instruction is higher than it should be. The embarrassing questions for deans and department heads is, *If the material is the much the same across all engineering schools and has not changed all that much for 30 years at the introductory and intermediate levels, why is the process and productivity of education yet the same as that of 30 years ago? Could not there be a way to address these issues without diminishing the role of the faculty member and running aground on the rocky argument of quality-versus-quantity?*

With the implied challenges in these observations and questions and the rapidly developing capability of small personal computers and Internet communications technologies, the commitment was made by the senior author in 1996 to produce digitally oriented materials for the entire range of courses in the thermal-fluids stem of the mechanical engineering curriculum. The primary goal was to place the student more in the center of the learning process and to address productivity and effectiveness issues. Further, it was decided to produce these materials in way that makes optimal use of computer-based and Internet-based technology for delivery. A secondary goal was to address the issue of the universality of undergraduate courses in core subjects by producing materials that could be easily adapted to instruction in a variety of institutions and to more than one textbook.

OVER ARCHING PRINCIPLES FOR ON LINE COURSES

Based upon a review of an unsolicited proposal by the senior author for the on line course by the learning technologies/design production staff of College of Continuing Education (CCE), the decision was made to initiate the course development project in the spring of 2001. The primary factors in the decision to expend internal CCE resources on the project were quality and scope of the material that was initially presented for review, and the commitment of the senior author to the project.

Key elements in the development of on line courses are that a student at a distance cannot benefit from the professor's emendations during a lecture and that the lecture is to be a functional tool in the course rather than the centerpiece of the course. Within these parameters, the Internet can be used for the construction of knowledge through inquiry, communication, and construction. These types of knowledge constructs are particularly valuable for teaching the methods of a discipline such as engineering, which has established frameworks and methods for forming and solving problems. The pedagogical challenge is for students to learn how to effectively use these methods as independent adult learners.

Using a student-centered approach along with Web resources in an on line course, instructors can effectively meet this challenge. In their most narrow use, Web resources can be a source for facts. However, the real strength of the Web as an instructional tool goes beyond its use as a desktop digital library. It is through student inquiry, communication, and construction via Web-based learning tools that students construct the knowledge they need to form and solve engineering problems.

To effectively use a student-centered approach, online courses can be designed using constructivism, which has a different set of assumptions about learning than those of the traditional curriculum. In a constructivist design, learners do not just absorb and store up information to be delivered back to the instructor intact on the exam. Rather, they make tentative and guided interpretations of experience, elaborate on those experiences, and test those interpretations under various problem types and solution modalities. Constructivist learning environments support multiple perspectives and interpretations of reality, knowledge construction, and context-rich, experience-based activities (Kulacki et al., 2001). A constructivist framework that maps well to engineering education comprises learning activities anchored to a larger problem, learner-ownership of authentic tasks that reflect real-world complexity, learner-owned processes of problem solving, a learning environment that requires and challenges and requires thinking, encourages testing of alternative solution paths, and provides for reflection on content and process. When engaged in solving complex, authentic tasks that reflect the way that knowledge is used by practicing engineers, students are required to organize information and their experience to represent effectively knowledge about the world.

CONTENT AND COURSE STRUCTURE

The course design is based on the notion that the use of handwritten notes and white/blackboards are to be kept to a minimum and eliminated where possible. Thus the task of developing lecture materials began under this constraint and in a manner that best represented the normative presentation of the subject. The topical coverage in the course was first organized into major sections that represent what the senior author believes can effectively be presented in a one-quarter (10 week) course in heat transfer course of approximately 50 – 60 lectures.

Class lectures were organized into modules each representing a 50-minute lecture and to provide the means to shift the course toward a highly visual orientation. Thus graphical and artistic qualities in the presentation materials increased in value in achieving overall educational goals. PowerPoint® was the chosen software because of its near universal use, the ease of transfer from one computer platform to another and the flexibility it offers when revisions are made.

The overarching educational concept is to shift the educational process from the presentation of content that is reviewed by students afterward to presentations that are more like a discussion of key points of theory and application to engineering problems. To accomplish this, students are provided the lecture materials via a posting on a course site on the Internet. In some cases, a supplemental text accompanies the PowerPoint® materials, but this is not yet a uniform feature of all of the modules.[1] This operational procedure was a strategic decision to shift the responsibility for preparation for lectures more to the student, and it was assumed that the students would review at least once the materials prior to any given lecture. In the early stages of development, paper copies of the modules were provided, but this was abandoned in 1998-1999 as lecture and on line materials were improved.

Another factor in the course design was the decision of the department to combine the traditional three-credit quarter course in fluid mechanics with the four-credit quarter course in heat transfer when a change to the semester system of instruction was made in the fall of 1999. Thus, rather than gaining time for instruction in either subject as a result of the semester transition, a

[1] A linked text that promotes active learning is being developed in Academic Year 2002-2003.

premium was placed on time and concurrently the instructional process was challenged. Twenty-five instructional modules were thus developed to address specific topics in fluid mechanics to meet the requirements of the new combined course. At present, some 75 modules make up the course, along with several case studies and example problems.

Following the recommendations of Aichlmayr and Kulacki (1997) in their paper that discusses the general characteristics and desired form of technology-enhanced educational materials, the major structural elements of the course include: a modular presentation all topics, a glossary of key terms and definitions, an equation library, a set of case studies and activities, supplemental text material when possible, and a utilities bin that contains a computational engine, data sets and Internet links. Not all of these elements are developed to the same degree as of fall semester 2002.

ON LINE COURSE DESIGN AND PRODUCTION

The general developmental goal for the on line course was to migrate the course form a passive to active learning mode. The first phase of this process was to produce material in a form that meets tests of improved instructional flexibility, is highly accessible to students, and is transferable between supporting texts. For example, in heat transfer, Internet-based materials should support instruction that uses texts by Holman (2002), Incropera and DeWitt (2001), Arpaci et al (1999), Krieth and Bohn (1997), and in fluid mechanics, the texts of White (1998), Young et al. (1997) and others. Also, it should be mentioned that cross-institutional adoption and sharing of the on line course materials would be a desirable future use of digital, Internet-based materials.

The CCE model for an effective online course includes several critical features: use of traditional and Internet-based resources, student activities (assignments, problems, projects, and papers), on line interactions with instructor and other students, and asynchronous and/or synchronous learning/teaching and assessment tools (quizzes, exams, etc.) All of these elements were built into the pilot offering of the combined course for the spring semester 2002. Face-to-face classes received the same material, and thus the on line and Internet materials served to supplement and enhance on campus instruction.

The current course materials are the result of development over a period of five calendar years and have been tested in face-to-face presentations in both the day and evening versions of the course. The content has been viewed by CCE as well organized, well defined in terms of a modular delivery scheme, and ready for the next stage of production. Overall the content was developed and refined to such an extent by the senior author that CCE could focus exclusively on issues relating to the on line presentation, production, and interactivity. This notwithstanding, all other elements of course yet needed to be developed and the commitment of considerable resources to even the first phase of the development was a necessity. Figure 1 presents several slides that illustrate the quality and variety of images contained in the modules.

The timeline for producing the final on line version of the course was relatively short. Production work began in mid-spring of 2001, and a pilot offering of the course was run in fall 2001 in connection with the face-to-face offering. Two critical objectives were to develop a uniform graphical design for all modules under the operative criterion that a student at a distance cannot benefit from the professor's on-the-spot emendations during lecture and to produce a narrative to accompany the visual material that would replace the traditional classroom under the criterion that the purpose of the lecture is to be a functional tool in the course rather than a centerpiece of the course.

The course narrative was produced in a radio studio by the senior author who presented his lectures without the use of a script, very much as lectures would be presented in a face-to-face presentation. A typical module containing 25 slides required 30 to 45 minutes of edited, real time recording. However, in the production process, this same module required one to two hours of review and fine-tuning before recording and release to the senior editor. Typically, audio recording requires studio time compared to actual presentation time of from 5:1 to 10:1, depending on the complexity of the material in a given module and the preparation of the author. For the present project, the senior author was able to reduce this ratio significantly owing to the extemporaneous delivery of the narrative material for all modules.

The hardware and software support environments included a Power PC with a 16 Bit audio card, Real Presenter Plus®, an 8x CD burner, a full size audio studio[2], and a large disk drive (10 MB/min) with backup capability (minidisk). QuickTime® was the software tool of choice because it facilitates synchronization of the audio and video, has chapter tracks on pull-down menus, and produces the capability for the viewer to progress quickly through the slides for either scanning or selection of a particular slide. This last feature is particularly useful in a first course in heat transfer and fluid mechanics owing to the large number of new concepts presented, the large number of empirical equations that must be included in the course presentation, and new (for the students) engineering design instrumentalities that have been reduced from practice and experimentation. In short, Quicktime® offers the most flexibility to the end-user.

Additionally, Quicktime® can stream audio. After a brief pause to buffer the audio, it can come through a 56K modem in "real time". Thus, it does not require a long download onto the user's computer. This feature is crucial to the long-term success of the course and to any on line course for basic but difficult engineering subjects.

The QuickTime® modules are streamed to a user from a server in CCE. A link to the server appears on the course web site created on the server supporting WebCT-3.5

[2] UMTC has audio studios that in its student-run radio station.

maintained by UMTC. This web site also provides general course information, a discussion board and/or chat room, e-mail Internet links, assignments and solutions, and feedback to the students in general and individually. The site is flexible and can be updated and expanded at any time during the course. In fall semester 2002, the first edition of a CD-ROM (Kulacki, 2002) containing synchronized visual and narrative material was produced and provided to on line and on-campus students as a supplement. A downloadable set of the modules was also provided on the CD-ROM, as well as on the course web site (Kulacki and Sakamoto, 2002).

COST FACTORS

Overall development costs for this type of course are high both in time and actual outlays of funds for support staff. Table 1 presents our best estimates of time allocations to several key program tasks. The single most costly element is incurred far upstream of course production in the content development phase when faculty expertise in both the subject matter and instructional technique are used. Typically, faculty time, unless supported by external funding, is supported by institutional funds at the department level, as was the case here. Over the five-year development period, the senior author devoted approximately ten percent of his time outside of normally assigned teaching, research and service duties on development and refinement of the 75 topical modules of the course.

Time allocated to various support and production functions by the CCE staff reached 50 to 60 percent of that for content development. It should be kept in mind that in this project, production time was much less than normally required owing to the relatively high efficiency with which audio was captured.

It should be expected that the cost structure for content development and production of engineering courses of similar scope and complexity would be similar to those encountered here. For content providers who either need a fully scripted narrative or who experience any difficulty with the recording process, the production costs might equal or exceed content development costs.

One of the major future tests for on line instruction is whether over time developmental costs can be recovered under a pricing structure that is affordable to students. A related matter is how educational activity focused on distance education will be managed at the departmental level and accounted for in the budgeting process of the university.

LESSONS LEARNED

The most important lessons learned over the past five years are that on line education in mechanical engineering is a vastly different activity than live, face to face instruction in the traditional classroom. Additionally student receptivity and responsiveness to constructivist pedagogy and adult learning modalities are not as strongly established as might be assumed.

Our experience is that enrollments in the on line sections of the course have been low, and most students yet prefer instruction centered on print media facilitated by day-to-day contact with an instructor and/or teaching assistant. On the other hand, this on line course has been used in academic programs that span the country, and several more years of offering the course will provide the important test for its viability and sustainability.

Student attitudes toward on line education have been less than enthusiastic even though a healthy respect appears to exist for the power and convenience of digitally formatted material. We believe that the assumptions about adult learning behaviors and constructivist pedagogy will be put a demanding test over the next several years.

REFERENCES

Arpaci, V. S., Kao, S-H., and Selamet, A., 1999, *Introduction to Heat Transfer*, Prentice Hall, Upper Saddle River, New Jersey.

Incropera, F., and DeWitt, D., 2001, *Fundamentals of Heat and Mass Transfer*, 5th Edn, John–Wiley, New York.

Krieth, F., and Bohn, M. S,1997, *Principles of Heat Transfer*, 5th Edition, PWS Publishing, Boston.

Kulacki, F. A., and Aichlmayr, H. T., 1997, “Toward a Universal Structure for the Implementation of Technology in Engineering Education,” *Proceedings*, Ninth Annual Conference, Technology-Based Engineering Education Consortium, William C. Norris Institute, Bloomington, Minnesota.

Kulacki, F. A., J. S. Swope, J. S., Oberg, L. J., Reardon, R., Ballard, J. K., and Anderson, C. V., 2001, An On Line Course in Heat Transfer and Fluid Mechanics: The Developmental Process, Proceedings, Anneal Meeting, North Midwest Section, American Society of Mechanical Engineers, University of North Dakota, September 28-30.

…Kulacki, F. A., 2002, *Heat Transfer and Fluid Mechanics*, *A First Course*, CD ROM, College of Continuing Education, University of Minnesota-Twin Cities.

Kulacki, F. A., and Sakamoto, H. 2002, ME 3322 Heat Transfer and Fluid Flow Course Web Site (Available at: www.umn.edu/courses/me3322/)

White, F. M., 1998, *Fluid Mechanics*, 4th Edition, McGraw-Hill, New York.

Young, D. F., Munson, B. R., and Okiishi, T. A., 1997, *Fluid Mechanics*, John-Wiley, New York.

Table 1. Estimates of resource requirements to produce the on line course in heat transfer and fluid mechanics 1997 to 2002. Funding for the content provider (faculty member) was provided from salary funds in the Department of Mechanical Engineering and was thus subsumed under instructional activity. All other resources were provided from the College of Continuing Education, an independent business unit of the University of Minnesota

Content provider	1000 hours (1977 – 2000) for ~ 2000 PowerPoint® slides in ~75 modules 200 – 300 hrs (2000-2001) for review during the editing & production processes
Instructional Designer	30 hours
Audio Production	100- 120 hours of studio time and 100 hours, production of CD-ROMs
Editing	180 hours
Media Producer	100 - 150 hours (1 – 1.5 hours/module)
Teaching Assistant	150 - 200 hours

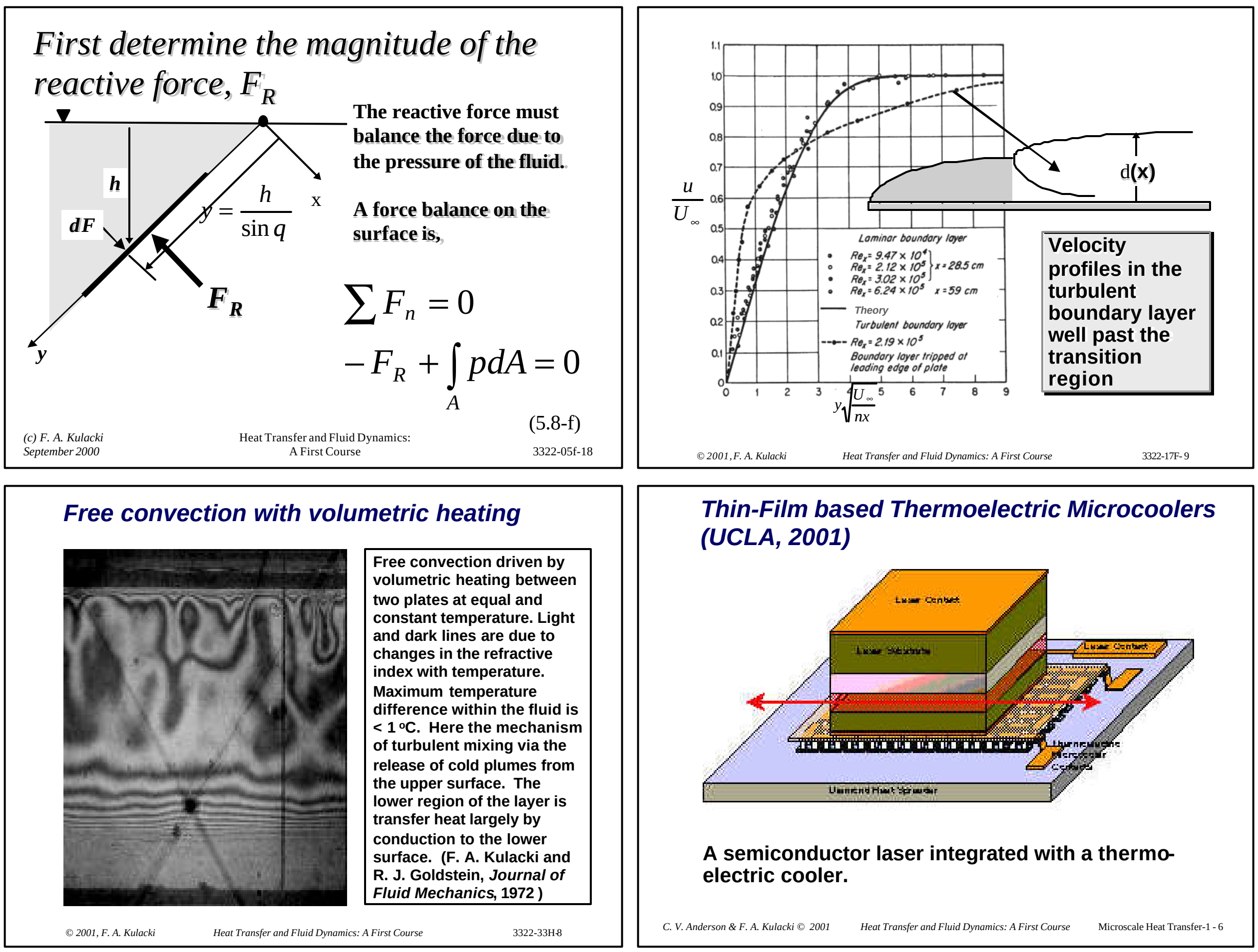

Figure 1. Individual slides from the on line course in heat transfer and fluid mechanics. Upper left: A diagram taken from a module on fluid statics that deals with forces on submerged surfaces. Upper right: A data plot taken from a module on laminar and turbulent external boundary layers. Illustration compared Blasius' solution to data in the laminar case. Lower left: Taken from a module on free convection in enclosures. The picture is an interferogram of free convection with uniform internal energy generation. Lower right: An illustration of a micro-electronic system with an integrated cooler taken from a special topical module on micro-scale heat transfer.