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On Developments in Interactive Web-based Learning Modules in a Thermal-Fluids Engineering Course: Part II*

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In this paper we present the general features of the project known as I-Campus, developed for enhancing the traditional lecture format in subject 2.005 Thermal-Fluids Engineering I, a core second-year subject in the Mechanical Engineering curriculum at the Massachusetts Institute of Technology (MIT). This new methodology utilizes computer-based teaching and learning models. We also introduce the pedagogical basis for the study and then present the details of the fundamental characteristics of the study together with the new learning technologies derived from them. We then illustrate the manner in which we have incorporated these new materials of the study.

INTRODUCTION

WITH DEVELOPMENTS in virtual technologies, web-based learning environments undeniably are changing classical classroom perceptions resulting in new teaching methods. Many of these changes are the result of the development of technology-enabled learning interfaces in the educational environment. Web-based learning systems are flexible with multiple learning media such as text, graphics, audio, video, animation and simulation, and provide an opportunity to accommodate multiple learning models such as apprenticeship, incidental, inductive, deductive, and discovery. Along with these developments in web-based education, it is essential to consider the change of the interface of education as well as the pedagogical nature of education based on media objects as new virtual technologies. However, a number of issues arise in using these new technologies in education. Two of the more important issues are the framework of the web-based educational model and the framework of the pedagogical learning method. Selection of a model to be implemented in a web-based course is of paramount importance as well as the pedagogical basis of an on-line course. We believe that the detailed studies related to these questions will identify the fundamental characteristics of web-based courses. In this paper, as the second part of our study [1], we present an implementation of one pedagogical model to be explained below, that was developed as part of an initiative known as the *I-Campus* Project/2.005 Thermal-Fluids Engineering I. We will present its features as an example of the framework of a web-based education model.

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Several studies on web-based course models may be found in the literature. Wallace and Weiner of MIT developed a general web-based structure and investigated the best way to use traditional lecture time given the availability of effective web-based courseware for introducing course materials in the classroom [2]. Ridwan, Yap, and Mannan of the University of the Singapore [3] also conducted a similar study. They introduced a comprehensive method of teaching a thermodynamics and heat transfer course based on web-based modules. Gosman, Launder, and Reece of Imperial College designed computer-assisted course modules for heat transfer and fluid flow in their study [4]. There have also been attempts to provide hypermedia-based teaching of fluid mechanics that have also been adapted to the WWW paradigm. Fay and Sonwalkar produced the Fluid Mechanics Hypercourse, which included many enhancements and video demonstrations for teaching fluid mechanics [5].

PEDAGOGY

Pedagogy refers to the educational methodology used for the teaching and the learning processes. Pedagogical models enable exposition of the subject content in many different learning pathways. In the case of interactive web-based learning modules, it is essential to define and exploit pedagogical strategies. Sonwalkar [6] described a framework for an enhancement of both on-campus and distance education by providing a 'learning cube' that combines media, learning models, and interactivity as the three principal dimensions of effective on-line learning.

The 'learning cube' consists of six different media components, namely, text material, graphics, audio, animations, movies and simulations, with five functional learning styles, namely:

- *apprenticeship* (step-by-step learning path);
- *incidental* (based on events prompting the learning experience);
- *inductive* (introducing a concept by a specific example leading to discussions of broader topics);
- *deductive* (based on stimulating the discernment of trends by introducing media objects);
- *discovery* (based on hands-on simulated environments).

Flexible learning environments derived from the WWW have created learning models that enhance classroom lectures and thereby facilitate student learning. The on-line learning modules enable opportunities for students to enhance their learning experience by choosing the learning media and learning model that work best for them. For the current project, the 'learning cube' is represented in 2-D for the media and the learning model elements that we have included for the study of the course. The 2-D representation of the 'learning cube' for the project presents its relationship with the lecture/learner trajectory that grows with the inclusion of media in the more advanced learning models: e.g., deductive and discovery. In this approach, the learning-path scales in the lecturer-learner axis relative to its involvement with media and learning styles. Each component of each learning style, based on media objects for a web-based course, is given below:

- *Apprenticeship*: text, graphics, audio, and video.
- *Incidental*: text, graphics, audio, and video.
- *Inductive*: text, graphics, audio, and video.
- *Deductive*: simulations, text, graphics, audio, and video.
- *Discovery*: simulations, text, graphics, audio, and video.

In these descriptions, text includes explanations, derivations, and descriptions; graphics includes explanations, descriptions, and examples; audio includes explanations and examples; video includes explanations and examples; and simulations include interactive numerical simulations for parametric studies and graphical simulations for mathematical equations.

ACTIVE LEARNING IN MECHANICAL ENGINEERING

The Mechanical Engineering Department at MIT has undertaken an initiative known as the *I-Campus* project to develop instructional and learning paradigms that will revolutionize its Undergraduate Program. As a part of the several advances in innovation, we intend to develop new instructional, learning and teaching models based on new technologies in the education infrastructure. The aim of this project is to leverage the course website as a supplementary teaching tool, by developing new content for 2.005 Thermal-Fluids Engineering I, a second-year course in thermodynamics, fluid mechanics, and heat and mass transfer, and by reorganizing the formation of the content for distance education.

The web-based course content consists of eight basic modules:

- *Thermal-Fluids Engineering: A Modern Technology*. Thermal-fluids engineering focuses on the utilization and deployment of energy resources to produce the goods and services of modern society. The thermal-fluids engineer is particularly concerned with the conversion of energy from one form to another in the most efficient manner practical, usually through the use of a fluid medium. This module serves as an introduction to the tools of a thermal-fluids engineer, which will be covered in detail throughout this site.
- *Energy and the First Law of Thermodynamics*. The introduction of the First Law of Thermodynamics, which is a generalization of observed facts about the energy interactions between a system and its environment. This section presents a generalized method for application of the first law, and a number of system models that are useful in framing our understanding of real systems.
- *Equilibrium and the Second Law of Thermodynamics*. The introduction of the Second Law of Thermodynamics and the 'run down to equilibrium'. This principle not only applies to mechanical systems running down under the action of friction, but also underlies the whole science of thermodynamics.
- *Simple Models for Thermal-Fluids Systems*. In this section, we define the two different kinds of models of fluid models that cover the spectrum from the uncoupled system to the coupled system; namely the incompressible fluid model and the ideal gas model. These models prove useful both for expanding our understanding of thermal fluid systems as well as for modeling the behavior of uncoupled and coupled systems. We also explore the differences between solids and fluids with emphasis on the fact that the only important role for solids in thermal-fluid systems is to provide the solid envelope to encounter the working fluid.
- *Work Transfer Interactions in Thermal-Fluids Systems*. In applying the First Law of Thermodynamics to real engineering systems, we have seen that there are two issues that need to be addressed: we must have a means to calculate the energy change of the system (the models of the previous section provide this) and we must have a means to calculate the energy interactions that caused this change in energy. In this section we focus on the work transfer interaction. To this end, we develop the quasi-static model and

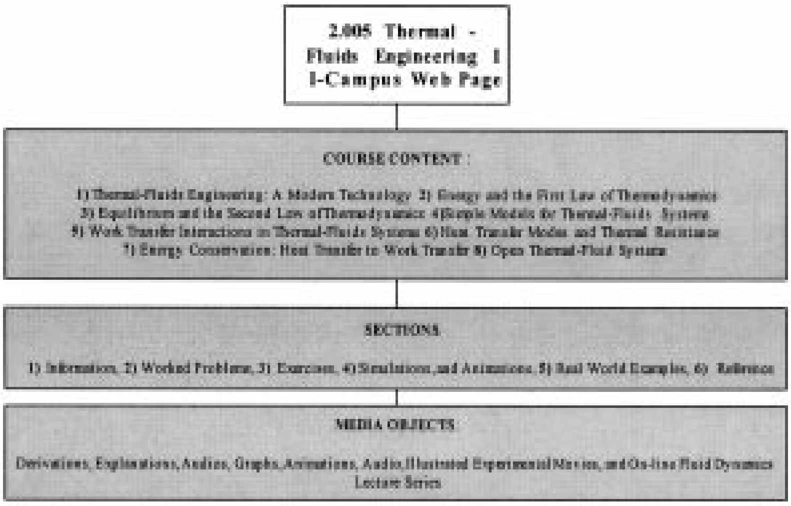

Fig. 1. 2.005 I-Campus web page schematics.

the notion of a reversible process. We also present a hypothetical means of executing reversible processes in an ideal gas. We further develop a collection of various reversible thermodynamic processes in the ideal gases model. The difference between reversible and irreversible processes is clearly illustrated.

- *Heat Transfer Modes and Thermal Resistance*. In this section we turn our attention to the heat transfer interaction. The specifics of a thermodynamic system determine which heat transfer modes are relevant to the analysis of the system. In this section we explore the heat transfer modes of conduction and convection. We are developing greater sophistication in our ability to analyze different geometries under both steady and transient conditions. Furthermore, we review the concept of thermal resistances and demonstrate its usefulness as an analytical tool to evaluate the heat transfer interaction in simple systems.
- *Energy Conversion: Heat Transfer to Work Transfer*. It is a straightforward matter to convert work transfer to heat transfer through simple dissipation. For the conversion of heat to work transfer, the process is not so simple since the heat transfer interaction carries both energy and entropy, whereas the work transfer carries only energy. We consider the implications of the Second Law of Thermodynamics on energy conversion processes, and formulate the second law in both an abstract as well as a practical sense.
- *Open Thermal-Fluid Systems*. The class of thermal-fluid systems known as open systems is considered. Since such systems do not contain a fixed quantity of matter of known identity as the closed systems did. To accommodate the transfer of matter across a system boundary, we adopt an alternative point of view, namely, the Eulerian approach. This method examines what happens to a large collection of fluid particles as they move through a specific location in space. Integral formulations of physical laws (such as the conservation of mass, the equation of linear momentum, the angular momentum equation, and the First and the Second Laws of Thermodynamics) are developed to aid our study of the behavior of these open thermal-fluid systems.

Each of the web-based learning modules described briefly above is divided into six different sections: the information section (on-line text and theoretical derivations), the simulation section (*Java*-based simulations developed for various topics covered in the module), the worked problems section (problems with complete step-by-step solutions which also employ simulations whenever possible), the exercises section (problems for the student to solve independently), the real-world examples section (development of models to describe real engineering systems), and the reference section (supplementary materials for extra study and review). However, *Open Thermal-Fluid Systems* consists of additional sections: namely, illustrated experimental fluid mechanics and on-line fluid dynamics lectures. Students can reach all media objects through *information* sections, direct connections to the simulation, and movie-related subsections, shown in Fig. 1 as a schematic of the course structure. It should be noted that these sections do not simply stand alone, but are interdependent. For example, a worked problem solution or a reference section might require a simulation, an animation, an experimental movie or an on-line lecture from another section. Direct links to these media objects are therefore provided. All sections are connected to each other by hyperlinks.

In addition, the Stellar course web page designed and supported by Academic Media Production Services (AMPS) and Academic Computing of MIT for instructors who want to use a website

Fig. 2. Discussion board section of 2.005 Stellar web page.

for their class materials provides a framework for putting the course content and other materials on the web, which has the following subsections:

1. *Course announcements*. Stellar keeps track of announcements related to the course, and makes it easy for students to see the latest ones on the 2.005 course home page. Older announcements are archived on a separate announcement page.
2. *Documents*. Faculty members can limit access to their documents by designating them as 'staff only' to permit working documents and similar materials to be on the site, unseen by other participants.
3. *Course material transfer*. Stellar administrators can easily copy materials between courses, allowing content from an old course to be copied into a new one.
4. *User administration interface*. Administrators, faculty and teaching assistants can manage class lists on the Stellar website by adding or removing students to match the names of those who are enrolled in the class.
5. *Discussion section*. Stellar encourages interactive participation in a discussion panel. Faculty, teaching assistants and students can easily set up forums, posting their messages on a web site, all participants can then initiate discussions and reply to these messages. Here, Fig. 2 shows the discussion board prepared for the web-based course, which offers a threaded discussion opportunity for faculty members and students. In addition, the course materials mentioned above may include a class list, staff list, syllabus, course material, homework, announcements, etc. Figure 3 shows sections of 2.005 Stellar framework schematically. More detailed information can be found at http://stellar.mit.edu.

A description of each section of a learning module follows.

INFORMATION SECTION

This part of the module contains textbook-style derivations that go beyond what is covered in the lecture. As is well known, a textbook material in the conventional sense is sequenced in terms of chapters, sections, subsections (including derivations), examples, exercises, explanations, graphics, appendices, and reference sections. However, the web-based course content is defined in terms of the course arrangement hierarchy. In an on-line course it is not necessary to use all text material given in the textbook. This section may have a negative impact on learners if the online course content consists of only derivations and explanations

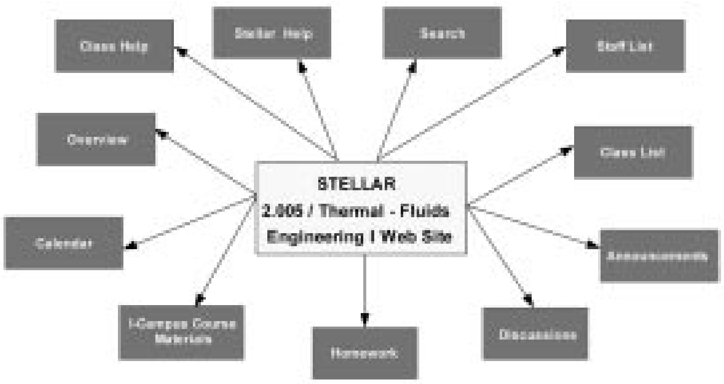

Fig. 3. STELLAR/2.005 Thermal-Fluids Engineering I course web page schematics.

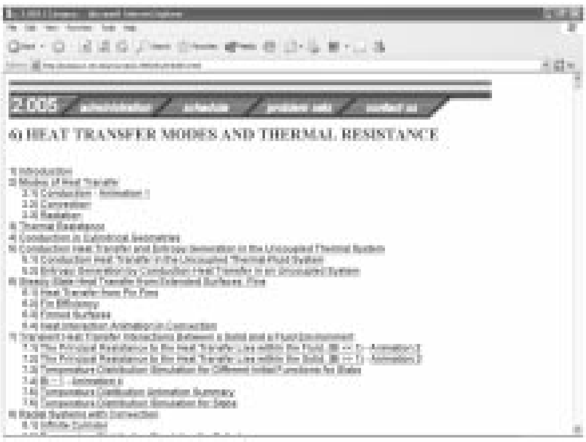

Fig. 4. Information section with hyperlinks.

similar to the classical course material. It is very important to point out that text material should be supported by a set of simulations, animations, and movies, which provide the interactive learning interface between instructors and learners. In order to create the interaction between instructors and students, the text material needs to be designed around content objects that are presented in the multiple learning styles developed in the hypermedia environment. In the current study, the text material providing the theoretical basis and fundamental concept of the study is based on lecture notes titled *An Integrated Approach to Thermodynamics, Fluid Mechanics, and Heat Transfer* [7]. In the study, parts of the lecture notes were used and additional sections were added to the web-based course material, such as Bessel functions and advanced topics in fluid mechanics. In contrast to the classical lecture style, our proposed lecture style consists of the following media objects, in addition to pure text materials, as defined in the pedagogical learning and the teaching cube: derivations, explanations, graphics, animations, simulations, illustrated experimental fluid-mechanics movies, and on-line fluid-dynamics lecture series.

In spite of the fact that these media objects provide powerful tools to design a web-based learning and teaching module, the important questions are concerned with the most effective manner to incorporate the style of using media objects in a web-based module. One of the key issues in this kind of web-based education design is the most effective means to apply the pedagogical learning cube. In the present case, we have followed the framework and the media-sequencing models of the learning styles described earlier. Figure 4 shows the information section of chapter six, *'Heat Transfer Modes and Thermal Resistance'*. The hyperlinks enable fast connections among the media objects of the module, and make it possible to use a few of them at the same time. This is one of the most important properties of hyperlinks related to the main purpose of the study. As seen in this figure, the content of the chapter similar to the classical textbook content is displayed as hyperlinks. The content of the chapter consists of the classical subsection titles and media objects such as simulations animations, etc.

Figure 5 shows the information section with text materials and graphics interfaces. The text material includes explanations and derivations similar to a conventional textbook. The text information is supported by graphics prepared for the corresponding content. Figure 6 shows the combination

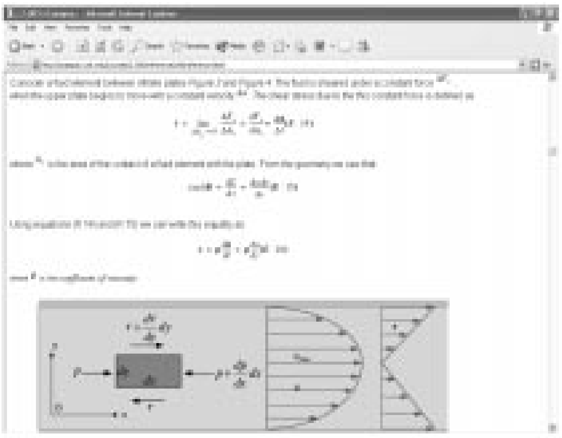

Fig. 5. Explanations, derivations, graphics.

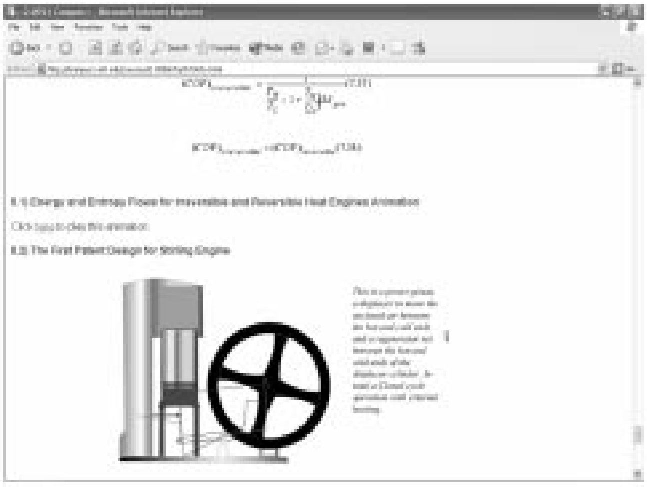

Fig. 6. Explanations, derivations, animation.

of text material, including explanation and derivations, with animation presenting the first patent design of the Stirling engine. This animation is presented in the content after the derivation, explanations and related graphics interfaces of the topic, '*The Effect of Irreversibility on the Performance of Heat Engines and Heat Pumps*'.

Simulations

Computer-based simulations are one of the great strengths of the web-based course design. The simulations provide a visual and parametric environment for the physical understanding of complex phenomena. Frequently, the scientific concept of a physical phenomenon is expressed on a theoretical basis that does not always lead to full understanding. Many classical problems and physical situations lend themselves to simulation of the underlying mathematics in a way that facilitates understanding the essential concept more completely while at the same time allowing observation of their dynamics. However, computers provide exceptional ways of experiencing phenomena related to academic education in many areas, and computer programs can be used for simulations of complicated physical situations defined in many classical problems. In addition, simulations provide a risk-free learning and teaching environment for understanding the consequences of changing several parameters in place of real situations. Since many physical phenomena are invisible to the naked eye, learners have not developed for the ability to visualize such complex phenomena as temperature distributions, stress distributions in a beam, gas laws, population movement, electric fields and magnetic fields. Simulations can motivate students in a creative and productive way to improve their perceptive and cognitive abilities for understanding and solving problems in their academic or real life. In addition, simulations developed by both numerical and analytical methods provide the environment for enhancing cognitive and intuitive understanding. Some studies [8] in the educational area show that these environments affect the learning outcome with respect to the quality of simulations and the style of interaction.

The simulations developed for the project are based on the *Java* programming language, which was selected for various reasons for the study. *Java applets* (or *simulations as html files*) can be run on different platforms with different operating systems. These applets require version 1.30 of the *Java* plug-in, and this software can be freely downloaded from the related web page. It is also possible to download this software for different operating systems from the same web source. These simulations are supported and executed by the student's web browser, and thus they are easily integrated into any web-based learning environment.

The detailed description of the simulations developed for the project is given in reference [1] as the first part of the current study. Here, we introduce a brief description of simulations on some properties. The mathematical basis of these simulations is the general solution of the one-dimensional heat-conduction equation written in the following dimensionless form for different geometries (slap, sphere, and cylinder)

$$\frac{T - T_i}{T_\infty - T_i} = \sum_{n=1}^{\infty} A_n e^{-\lambda_n^2 Fo} F_n(\lambda_n \eta) \qquad (1)$$

and the general form of the fractional energy loss values for three different geometries is given as:

$$\Phi = 1 - \sum_{n=1}^{\infty} A_n e^{-\lambda_n^2 Fo} B_n \qquad (2)$$

where $A_{\rm n}$, $B_{\rm n}$, $F_{\rm n}$, and the corresponding transcendental equation for each geometry are given in Table 1. In this table, J_o and J_1 are *Bessel* functions of the first kind, of orders 0 and 1, respectively, the parameters λ_n ($n = 1, 2, 3, \ldots$) are roots of the

Table 1.

Geometries	A_n	B_n	$F_n(\lambda_n \eta)$	Transcendental equation
Slab	$\dfrac{2\sin\lambda_n}{\lambda_n + \sin\lambda_n \cos\lambda_n}$	$\dfrac{\sin\lambda_n}{\lambda_n}$	$\cos\left(\lambda_n \dfrac{x}{L}\right)$	$\lambda_n \tan\lambda_n = Bi$
Cylinder	$\dfrac{2J_1(\lambda_n)}{\lambda_n(J_0^2(\lambda_n) + J_1^2(\lambda_n))}$	$2\dfrac{J_1(\lambda_n)}{\lambda_n}$	$J_0\left(\lambda_n \dfrac{r}{R}\right)$	$\lambda_n J_1(\lambda_n) - Bi J_0(\lambda_n) = 0$
Sphere	$2\dfrac{\sin\lambda_n - \lambda_n\cos\lambda_n}{\lambda_n - \sin\lambda_n\cos\lambda_n}$	$3\dfrac{\sin\lambda_n - \lambda_n\cos\lambda_n}{\lambda_n^3}$	$\dfrac{\sin(\lambda_n r/R)}{\lambda_n(r/R)}$	$1 - \lambda_n \cot\lambda_n = Bi$

corresponding transcendental equation, η is characteristic length, L is the slab half-width, R is the cylinder or sphere radius, F_0 is the Fourier number, and Bi is *Biot* number [7, 9].

The course contains twenty simulation programs and five calculator programs [1]. The simulations include, for example, temperature distribution simulations for slabs, spheres, and cylinders immersed in a fluid, a convective heat transfer simulation, a surface energy pulse simulation, and a periodic variation of the surface temperature simulation as semi-infinite solid models. There are also simulations of the fractional energy loss versus Fourier number, as well as versus the Biot number; and the centerline temperature simulation versus Fourier number. Five calculators have been developed to allow the students to quickly calculate values that they might need for their problem sets, such as Bessel functions and a transcendental equation solver. The simulations that display the results described are presented with images of their graphical interfaces. Figure 7 shows an example of these simulations. In this program, the roots of the transcendental equations, including the Bessel functions, are shown in the text file located in the bottom of the interface. The first Biot number is calculated with respect to the physical parameters entered by the user; values of the Biot number 2 and the Biot number 3 are set directly by the user in order to compare temperature distribution profiles for different Biot number values. In the program, the solid is assumed to be at a uniform initial temperature and then is plunged into a fluid at a different temperature at $t = 0$ sec. The simulation program gives the temperature distribution history subsequent to $t = 0$ sec. The graphical interface for the simulation that calculates the temperature distribution for different geometries as a function of time is shown in Fig. 7 (for the cylinder geometry).

The input-output interface for the simulation is

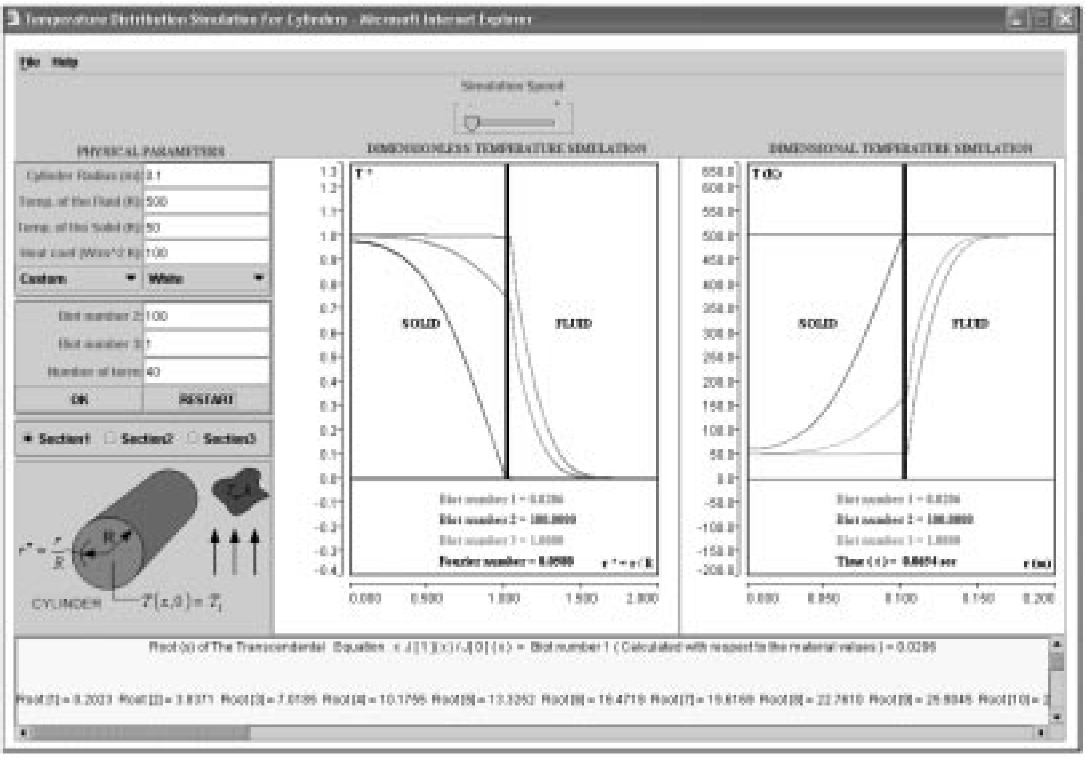

Fig. 7. Temperature distribution simulation (applet) developed 100% in Java for the cylinder geometry.

separated into a number of parts. The part of the physical parameters of the display (the upper left-hand corner of Fig. 7) allows the learner to input the characteristic dimension of the solid, the initial temperatures of the solid and the fluid, and the heat transfer coefficient between the solid and the fluid. A pop-up library of twenty-three materials can be accessed by clicking the Material menu, which also contains a Custom option in which the student can specify the density, the thermal conductivity, and the specific heat capacity of the solid object.

The Section 1, Section 2, and Section 3 menus located above the cylinder icons allow the student to choose the output graphs of the simulation. The Section 1 option consists of plots of the spatial temperature distribution evolving with time; the Section 2 option is similar, but replaces the dimensionless temperature graph with a dimensional graph of the centerline temperature versus time; and finally, the Section 3a option consists of a dimensionless graph of the centerline temperature versus time and a spatial temperature distribution simulation, convenient for the small Biot number case. As the temperature distribution in the solid is uniform and the numerical solution is not convenient, a lumped parameter model is used (the Section 3b option in Fig. 7).

Videos

Videos can also be used as media objects in a web-based learning lecture. Videos are the media-based virtual environments to illustrate a given theoretical description. In the past, there were problems such as bandwidth cost and quality issues related to videos but with the latest technologies—for example, video compression developments and real-time streaming technology—videos should be considered as an important part of web-based education modules.

The video section of the study consists of two parts. The first part includes the experimental illustrated fluid mechanics movie files prepared under the direction of the National Committee for Fluid Mechanic Films (NCFMF). These movies are already available in the Barker Engineering Library at MIT as VHS tapes with 16-mm sound films. NCFMF is a self-constituted group of eleven university faculty members who are interested in fluid mechanics. The main aim for developing these films was to provide a suitable and an influential way of filling a serious learning gap in fluid mechanics. (This program was completed in 1969.) These are single-topic films that show a particular experiment or illustrate a phenomenon related to fluid mechanics, and are ideal for illustrating a specific subject of fluid mechanics. However, in order to incorporate these films into the new curriculum, we first had to obtain permission to reproduce the films in video and digital formats for the educational initiative the *I-Campus* project.

We then had to digitize them in a suitable form and incorporate them as digitized files with text materials, simulations, and animations in the web-based course by making them accessible on-line. Videos have been encoded for on-demand viewing in RealVideo format at a resolution of 640×480 and a bit-rate of 350 Kbps. The illustrated experimental fluid-mechanics section includes twenty-six movie files:

1. Low Reynolds number flow
2. Eularian–Lagrangian description
3. Pressure fields & fluid acceleration
4. Channel flow of a compressible liquid
5. Fundamentals: boundary layers
6. Turbulence
7. Secondary flow
8. Rotating flows
9. Waves in fluids
10. Surface tension in fluid mechanics
11. Deformation of continuous media
12. Vorticity-Part I
13. Vorticity-PartII
14. Stratified flow
15. Cavitation
16. Flow visualization
17. Rheological behavior of fluids
18. Boundary layer control
19. Fluid dynamics of drag-Part I
20. Fluid dynamics of drag-Part II
21. Fluid dynamics of drag-Part III
22. Fluid dynamics of drag-Part IV
23. Rarefied gas dynamics
24. Aerodynamic generation of sound
25. Flow instabilities
26. Magneto-hydrodynamics.

The on-line lecture section includes three parts and thirty-nine lectures (Fig. 8) (by Professor Ascher Shapiro, Emeritus Professor of Mechanical Engineering at MIT). These parts are:

- *Concepts, principles, and flow phenomena due to inertia:*
  - Introduction to the subject of fluid dynamics
  - Hydrostatics
  - Surface tension
  - Kinematics of fluid motion
  - Conservation of mass
  - Introduction to inviscid flow I: Bernoulli's equation
  - Introduction to inviscid flow II: Bernoulli's equation
  - Control volumes and Reynolds transport theorem
  - The momentum theorem I
  - The momentum theorem II and the theorem of moment of momentum I
  - The theorem of moment of momentum II
  - Wave propagation I
  - Wave propagation II
  - Wave propagation III
  - One-dimensional steady flow
  - Compressible flow II
  - Free-surface channel flow.

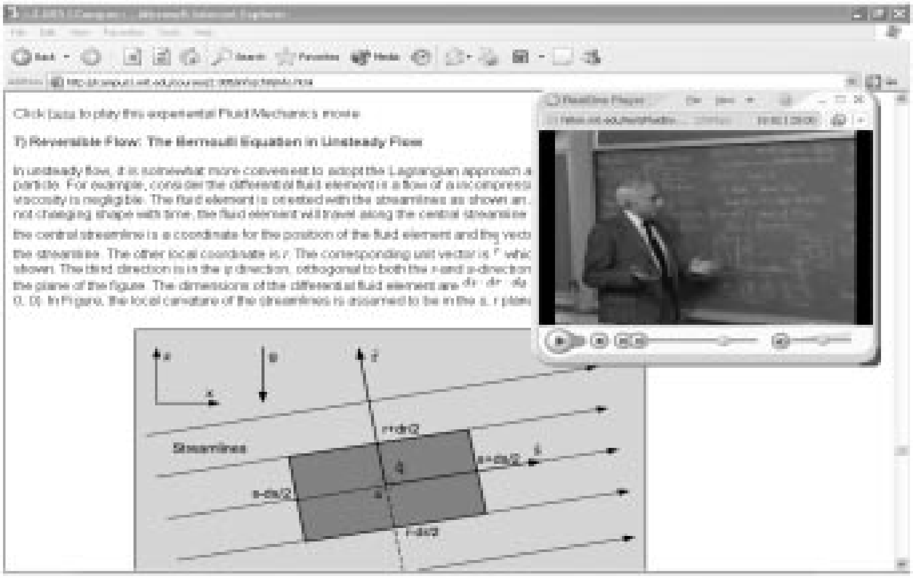

Fig. 8. An example of on-line fluids mechanics lecture series.

- *Viscous behavior:*
  - Quasi-parallel viscous flows I
  - Quasi-parallel viscous flows II
  - Quasi-parallel viscous flows III
  - The Navier-Stokes equations
  - Dynamic similitude and model testing
  - Dimensional analysis
  - Inertia-free flows
  - Flows at high Reynolds number
  - The laminar boundary layer
  - Turbulence
  - Turbulent shear flows
  - Head losses in piping systems.
- *Deeper insights:*
  - Vorticity, circulation, and vortices
  - Kelvin's circulation theorem
  - Helmholtz's vorticity equation
  - Helmholtz's vortex laws
  - Potential flow I
  - Potential flow II
  - Lift
  - High-speed gas flow
  - Drag
  - Fluid dynamic instabilities.

Animations

Animations are low-cost alternative tools to videos, to present the main concepts of physical phenomena to learners. Actually, physical phenomena may explain concepts better than video clips can. However, animations and video presentations have different importance, based on interactive learning modules. The animations in the project are based on Flash technology that gives a number of opportunities for presenting them in a web-based module. The animations developed for the *I-Campus* project are the convection animation, the temperature profilers' animation for different Biot numbers, the reversible and the irreversible heating and the cooling animation, the closed and the open systems animations, the Buoyancy-forces animation, the quasi-static thermodynamic process animation for the ideal gas, the pressure-wave propagation animation, the energy and the entropy energy-flow animation, the Stirling engine and Stirling cycle animations, the flow past a sharp plate plane animation for low and high Reynolds numbers, and developing velocity profile animation. For example, Fig. 9 shows how students define the stable and unstable case of an object immersed in a fluid with respect to the object's metacenter, buoyancy force direction, and the object's location of the center of the gravity.

This animation gives the stability or the instability situations of the object due to these three identities interactively. The animation in Fig. 10 presents a fluid with a uniform velocity distribution approaching a plate. Fluid flows past the plate; the no-slip boundary condition dictates that at the surface of the plate, the fluid velocity relative to the plate is zero. A slow-moving fluid layer, known as the boundary layer, forms over the

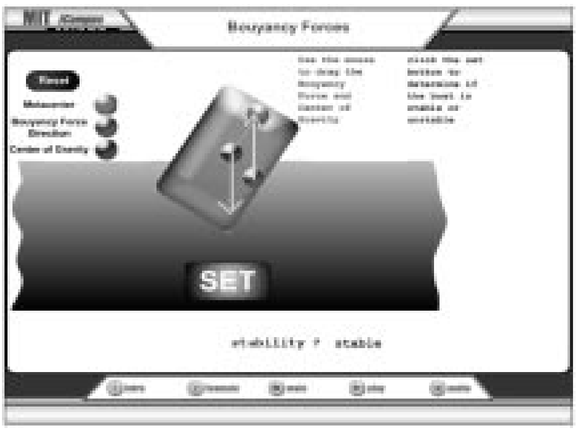

Fig. 9. Buoyancy forces animation.

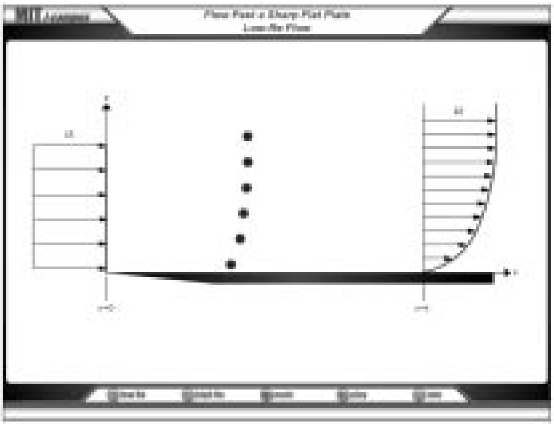

Fig. 10. Flow past a sharp plate animation.

plate where the fluid velocity makes a transition from the velocity of the solid surface (zero in this case) to the free-stream velocity. As is shown, the boundary layer on a surface is generally quite thin relative to the dimensions of the surface. Because the velocity changes from zero velocity to the free-stream velocity over a thin region, the transverse gradient in the velocity is large. As a result, there is substantial dissipation in the boundary layer, and the Bernoulli equation is invalid in the boundary layer. Students can observe this phenomenon for the low and the high Reynolds number cases by using this animation.

The last animation example in the section is the Stirling engine (Fig. 11) designed for the course 2.670, Mechanical Engineering Tools, using three-dimensional animations as an example of heat engines. During the course, students work with various machining tools to build a parallel split Stirling engine. This animation provides an important opportunity for students to observe this phenomenon by clicking on each component of the animation, including a short description and short clips of an operation of the engine, including four clips related to components of the engine: the pressure chamber, the heat sink, the flywheel, and the piston chamber, as seen in Fig. 11.

EXERCISES, WORKED PROBLEMS, REAL-WORLD EXAMPLES AND REFERENCE SECTIONS

Detailed information on exercises, worked problems, real-world examples and reference sections of the project can be found in reference [1]. Here we will briefly give the information about these sections.

- *Exercises*: consists of several problems developed to analyze the understanding of students, with each problem related to a corresponding chapter. This section can be thought of as the problem section of a textbook. It also includes media objects such as simulations and animations, which are connected to each other in order to help students with their problem sets.
- *Worked problems*: consists of several solved problems. Solutions include the classical analytical solution with derivations, explanations and graphs. In addition, the solution of the same problem is given by using appropriate simulations, movies or explanations of the problem in detail. Students can compare the classical solutions with the solutions obtained by simulation programs, and examine problems related to the course topics by real-world presentations. For example, Figs 12 and 13 show how the media objects are incorporated into the solutions of the problem set. Figure 12 shows the problem set and the solution of a cavitation design problem, which is defined as the process of formation of the vapor of a liquid when it is subjected to reduced pressures at constant ambient temperatures. It is also a major problem in submarine propellers. In our case, first the definition of the problem is given by explanation and then an experimental movie follows this part of the solution, which is related to cavitation. The clip in Fig. 12 shows one type of cavitation that is the beginning case of this phenomenon because of higher flow speeds at near-minimum pressure line. Before the solution of the problem,

Fig. 11. Stirling engine and its components animation.

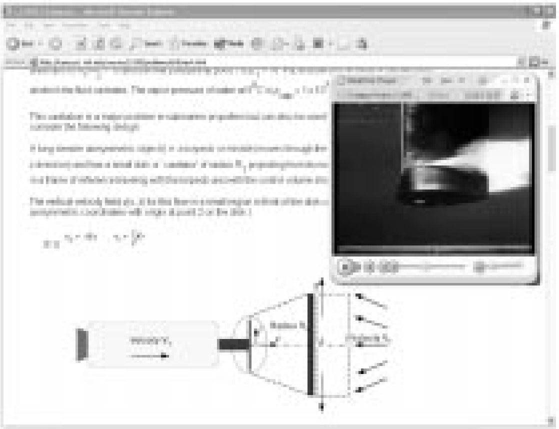

Fig. 12. A worked problem combined with a clip.

all cavitation concepts in fluids are given by this clip. Figure 13 shows another worked problem. The problem is first given by the explanations, the derivations, and the graphs; then the solution calculated by the related simulations programs is introduced after the classical solution. The solution part includes the solution of the problem by simulations and also examines the same problem with different material parameters and program options (see [1]).

- *Real-world examples*: provides students with the ability to model and design real engineering systems, and to strengthen their skills through modeling designs for various cases appropriate to the material in the module.
- *References*: organized as an appendix section of the chapter in a classical sense. This section includes all media objects with text material. Topics not given in the information section are given in this section. For example, additional related values, calculators, and tables can be found in the reference section of each module.

CLASSROOMS AS A PART OF INNOVATIVE EDUCATION

We believe that classrooms are an important part of web-based learning modules, since the implementation of these modules can be achieved successfully in a lecturer-student interaction via the well-equipped classrooms. In that sense, the innovation in the classrooms, based on new technologies, goes beyond the classical definition of the classroom. Such classrooms should provide the necessary equipment to put into practice all web-based course materials in the lectures and the recitations. To this end, the Department of Mechanical Engineering has been rebuilding classrooms with respect to developments in web-based learning technologies. Some classrooms have been rebuilt with equipment that provides the course web components during normal course hours. This innovation includes modular tables that can be configured to a lecture-style, with tables in rows; or a lab-style configuration, allowing students to work in groups of two or more, on media objects, wireless network connections, multiple network power outlets, several projectors, and Ethernet drops. In addition, another initiative is still in progress, the main purpose of which is to provide a laptop for each student. This will allow students to connect to the web-page-related course materials by the wireless access (IEEE 802.11b-compliant technology) not only in the classrooms, but also across the campus.

CONCLUDING REMARKS

In this study we presented a sample model for a web-based learning and teaching course based on a specific pedagogical method consisting of five components: apprenticeship, incidental, inductive, deductive and discovery, which can be used for other undergraduate courses, and also for graduate courses. However this study is a part of the *I-Campus* project and is still under development for several topics covered in 2.005 and 2.006 Thermal-Fluids Engineering I, II. The Department of Mechanical Engineering has already made several advances in innovation of its undergraduate education. Several courses for example reference [10, 11] have already been re-designed to

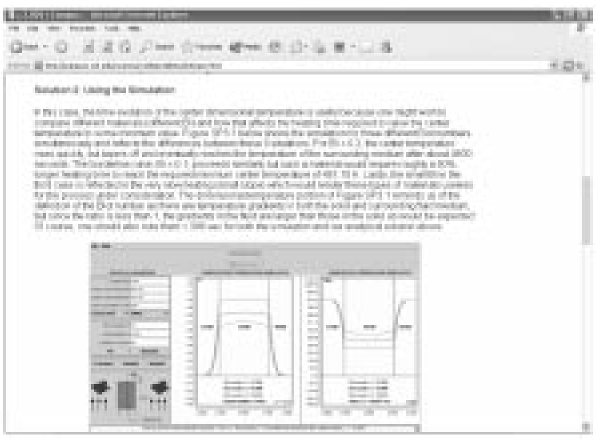

Fig. 13. A worked problem combined with a simulation.

reflect new thinking in learning and the teaching methods. As a part of these important changes in the department, we introduced new instructional and learning paradigms that transform the undergraduate program. We believe that it is necessary to exploit other advances in information technology and to restructure the content creation for distance education in order to maintain the quality of both undergraduate education and graduate education.

A limited amount of course materials have already been used in lecture and recitation in the last two terms. An assessment needs to be made also on the students' experience in the course, based on the learning aspect of the project. For this purpose, we are planning to implement all course materials in the lecture hours, providing an important opportunity for feedback on the project. We believe the feedback from the course students can be used to improve the quality of the modules developed in the project. In the coming terms, the course modules will be introduced in the classroom, in the lecture, and the recitation hours as supplementary lecture materials. Research studies related to assessment will be considered as a separate part of this project.

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