Int. J. Engng Ed. Vol. 11, No. 1, pp. 46–57, 1995
Printed in Great Britain.
0742–0269/91 $3.00+0.00

Interactive Multimedia Courseware on Manufacturing Processes and Systems

G. BENGU
Department of Mechanical and Industrial Engineering, New Jersey Institute of Technology, Newark, NJ 07102, USA

This article describes an ongoing study in improving entry-level engineering education through the deployment of new teaching and learning tools. A computer-aided interactive multimedia manufacturing courseware is described. The courseware is intended to introduce an early and comprehensive understanding of interdisciplinary applications of engineering systems with focus on manufacturing. The manufacturing engineering multimedia courseware will include on-line lectures, audio-video education tools, interactive computer software (process and equipment design, simulation and animation software), on-line assignment and exams, and information about faculty. It will also make access available to related academia, industry, and government research and education information through the 'world wide web'. Such a learning system is also believed to be a stepping stone on the process that generates and rewards 'active, independent, self-directed learning' for students to gather and assess data rigorously and critically.

1. INTRODUCTION

THIS STUDY describes a comprehensive plan for improving engineering education through the incorporation of manufacturing processes and systems (MP&S) as part of the curriculum [1]. Recent advances in computer and information technology [2,3] have enabled the development of new teaching and learning aids that are the subject of this article. The increased power of computers, the arrival of hypertext in multimedia, and the development of hypermedia browsers on the Internet makes it possible for the first time to introduce MP&S, through new teaching and learning tools that use such technology, in a comprehensive manner into the undergraduate curriculum. It is generally understood in academia that manufacturing is vital in today's global economy and that we need to prepare our students accordingly. The numerous manufacturing centers of excellence created to foster university–industry collaborations have certainly helped to promote manufacturing as an engineering specialization. More recently, universities and agencies such as the National Science Foundation have intensified efforts to extend, expand and promote manufacturing education at the entry level. However, manufacturing education has not sufficiently stressed the interdisciplinary nature of the subject. Consequently, the synergy of engineering disciplines in manufacturing is discovered too late in the curriculum to be meaningful in preparing students with a thorough understanding of MP&S.

This lack of emphasis on the synergy of the various disciplines in engineering education and the need to acknowledge the interdisciplinary aspects of engineering in general is very aptly traced by Hazelrigg [4]. Hazelrigg recognizes that from the early 1950s through to the 1970s there was a shift in emphasis from an 'apprentice-based' approach to an 'applied science' approach of engineering education where the basic sciences were stressed. It was left to the graduating engineer to pick up engineering experience on the job. We note that Hazelrigg's historical perspective of engineering education applies equally well to manufacturing education within the engineering curriculum. This study introduces new teaching and learning tools that address the issue of advancing synergy between engineering disciplines. Such a synergy in turn will help the students to associate the basics to real life and facilitate 'higher-order learning' in the following sense as described by Paul [5]:

> By helping students actively think their way to conclusions; discuss their thinking with other students and the teacher; entertain a variety of points of view; analyze concepts, theories, and explanations in their own terms; actively question the meaning and implications of what they learn; compare what they learn to what they have experienced; take what they read and write seriously; solve non-routine problems; examine assumptions; and gather and assess evidence.

This paper is organized in five sections. Following the introduction, the notion of 'courseware' is introduced in Section 2. Section 3 describes the high-level design of the courseware. Section 4 outlines the system integration issues. Section 5 offers a summary and conclusion. A glossary of some of the acronyms and special terms used in the article is provided in the Appendix.

2. THE COURSEWARE CONCEPT

In the current engineering curriculum, emphasis is placed on engineering fundamentals in the early stages of engineering education, as it should be. The current approach requires, in most cases, studying the building blocks (such as mathematics, physics and chemistry) before introducing the problem to be solved. However, in so doing the real-life engineering applications which capture the relevance of these fundamentals are left to the students to grasp in the final year, e.g. through senior projects. It is often by then too late for students to learn problem-solving techniques to solve problems related to complex systems and processes; the functional interaction between engineering disciplines and other allied topics such as global economics, social impacts, safety, environment, politics and global interactions within MP&S are usually not covered at all. Students receive little or no insight on how these issues relate to manufacturing as well as how they unite with engineering issues. At the same time teaching such issues can be very useful to educators in motivating students in engineering and guiding them to make an informed decision in choosing an engineering major.

In this study we hope to alleviate the aforementioned limitations of the current approach by introducing MP&S using real-world engineering applications and providing hands-on experience beginning at early stages of the engineering curriculum. Being able to perform complex, synergistic applications while they are trying to learn mathematical, physical and chemical principles, is an important motivation in student learning. Thus, computer-aided learning is a precursor to computer-aided design and computer-aided manufacture, which is heavily emphasized in engineering education [1]. The underlying premise is that equipping both faculty and students with effective education tools can empower both the faculty (by increasing their effectiveness in imparting knowledge) and the students (by enabling them to absorb better the role of individual engineering disciplines and how they come together to address real problems). It is hoped that as a result faculty, as well as students, are likely to be more motivated. At the same time this increased emphasis on MP&S in the early years will complement the senior projects in the current curriculum and contribute to prepare engineers better for US industry. Their problem-solving capabilities as individuals and as team members will be significantly improved. Another spin-off benefit of the learning and teaching system developed in this study is its usefulness in distance learning—a future trend in delivering education.

A primary reason for not introducing MP&S early in the curriculum was the unavailability of simple and affordable tools to illustrate complex, real manufacturing systems. In this study, we challenge this problem by proposing the use of interactive multimedia tools. Such tools are envisaged to be used as a complementary support system for traditional classroom teaching, but not as a replacement. These tools will enable the faculty to address complex issues with reduced requirement of previous knowledge or mastery, and present large volumes of information in a flexible and efficient manner—a task that would otherwise be exceedingly arduous or impossible using only classical teaching tools. An example would be the manipulation of complicated machinery through the use of simulation/animation and multimedia tools at a relatively low cost. Furthermore, the proposed tools will serve as an integrated delivery vehicle to support the long-desired aim of multi- and inter-disciplinary instruction and learning [6].

We use the power of multimedia technology, specifically, to assemble course materials in various media forms such as text, slides, full motion audio-video, live video and interactive software on a single, powerful, interactive platform, referred to hereinafter as simply 'courseware'. The courseware is in fact a unique design of a collection of learning and teaching tools that are organized to feature MP&S in a comprehensive manner. The courseware 'system architecture' is sufficiently open to feature other subjects besides MP&S. Courseware will feature information on MP&S topics. It will also include information from remote sites using Internet resources. There are major technological challenges to be addressed in fully implementing courseware, such as sharing video material over the network. Further advances in the National Information Infrastructure will enhance the delivery of such interactive multimedia courseware over the Internet [7,8]. More importantly, there are major educational challenges in integrating the courseware into the curriculum. Careful planning and organization will be required to provide access to the courseware for a large number of students. Students can easily get confused easily when numerous software programs, machines and manuals are involved as part of the instruction; one must guard against the unintended consequence of overloading entry-level students with information so as to completely overwhelm and disillusion them.

The design of courseware will be guided not so much by technology, but by the basic goals of engineering education, which include imparting a thorough understanding of the engineering fundamentals, as well as communication skills; fostering creativity and inquisitiveness; honing the ability to work effectively as individuals and in a group environment; and generating a desire to continue learning as a mechanism to respond and adapt well to change. The design of the courseware described in this paper is part of the Technology Reinvestment Project (TRP) sponsored jointly by the National Science Foundation (NSF) and the Advanced Research Projects Agency (ARPA). This project involves a broad cross-section of the engineering faculty as well as the humanities, management and computer science faculties, and is being executed at the New Jersey Institute of Technology, Newark, NJ.

3. HIGH-LEVEL DESIGN OF COURSEWARE

The courseware contains the course material, referred to as topics, prepared by expert faculty. Each topic contains illustrations in various media such as text, still pictures and slides, video and interactive software. The students invoke the courseware through a user-friendly screen by picking the 'manufacturing processes & systems' courseware option (see Fig. 1). The screen shown in Fig. 1 is designed to be a common front-end for launching other coursewares as they are developed and made available. Upon choosing the courseware, the students will be prompted by the 'user interface screen'.

An 'electronic blackboard' (see Fig. 2) serves as the primary interface between the courseware and the students. This interface can also be viewed as the basic framework for the courseware that brings together subject material assembled using various media. The 'topic panel', along the left edge of the blackboard, lists the topics such as simulated manufacturing systems, metal removal, forging, laser, among others.

This framework is intended to be an open architecture so that the topics can be added, deleted, modified and sequenced in any order as desired by faculty. The 'resource panel', across the top edge of the electronic blackboard, provides a menu of options for the students to access the associated course material for a chosen topic. Some typical options that are featured include course notes, factory floor laboratories and interactive integrated computer software, videos, on-line assign-

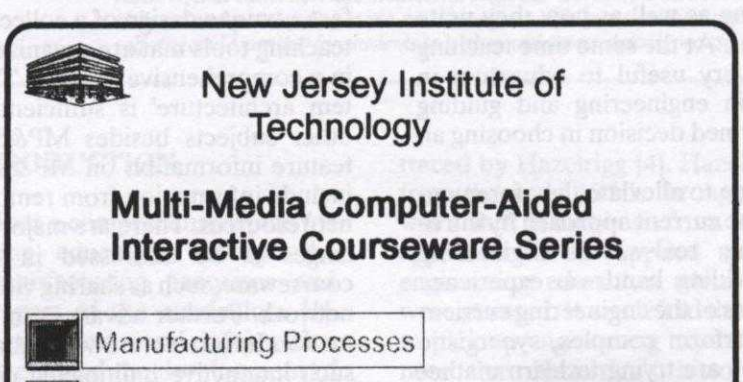

Fig. 1. User interface screen.

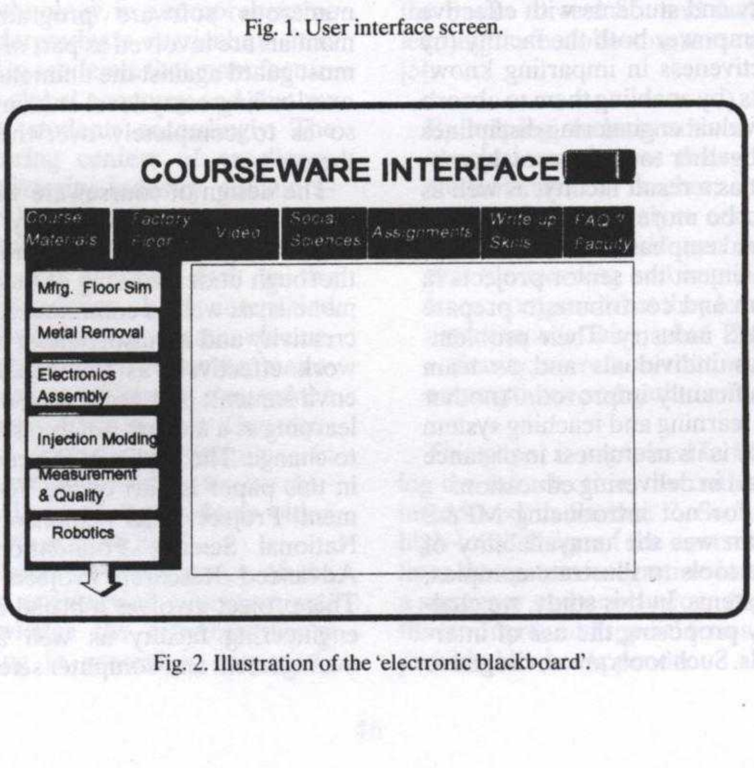

Fig. 2. Illustration of the 'electronic blackboard'.

ments and exams, social, management and economic issues, communication and writing skills, help and frequently asked questions, general information about faculty, and global networking with other research centers in universities and industry.

The principal elements of the framework are explained next.

3.1 Principal elements of the framework

The principal elements of the framework include the topics and the associated resources used to access the topics. Topics here refer to a broad variety of subjects on manufacturing processes and systems. Each topic content and material will be prepared by an expert faculty. The individual topics are not described here. However, the variety of resources featured in the courseware are individually described in the ensuing sections. The terms resources and options are used interchangeably.

3.1.1 Course material. The 'Course Material' resource will provide the students with access to faculty lecture notes. Thus students can peruse the lecture notes prior to the lecture and be prepared for class and /or review them after class at their own pace (see Fig. 3). This feature is particularly useful for students who have difficulty following the lectures due to language barriers or other learning difficulties; about 35% of incoming freshmen students to NJIT have a first language other than English. The lecture notes will be presented like the pages of a printed book, albeit interactive and online.

The cross-references in the text will be accessed through so-called 'hyperlinks' that are either underlined words or icons. *Hyperlinks* are essentially electronic links to cross-reference databases and are used to organize related information that is made available in different media [7,8]. Clicking on the hyperlinks allows the user to navigate easily to the cross-reference material that is simply linked electronically to the original document. When accessed initially, the lecture notes are depicted on screen in textual form. The cross-references here refer to any of the following: textual material, graphics or still pictures, videos and software. As can be seen in Fig. 4, the 'electronic assembly' drawing will appear if the student clicks on the

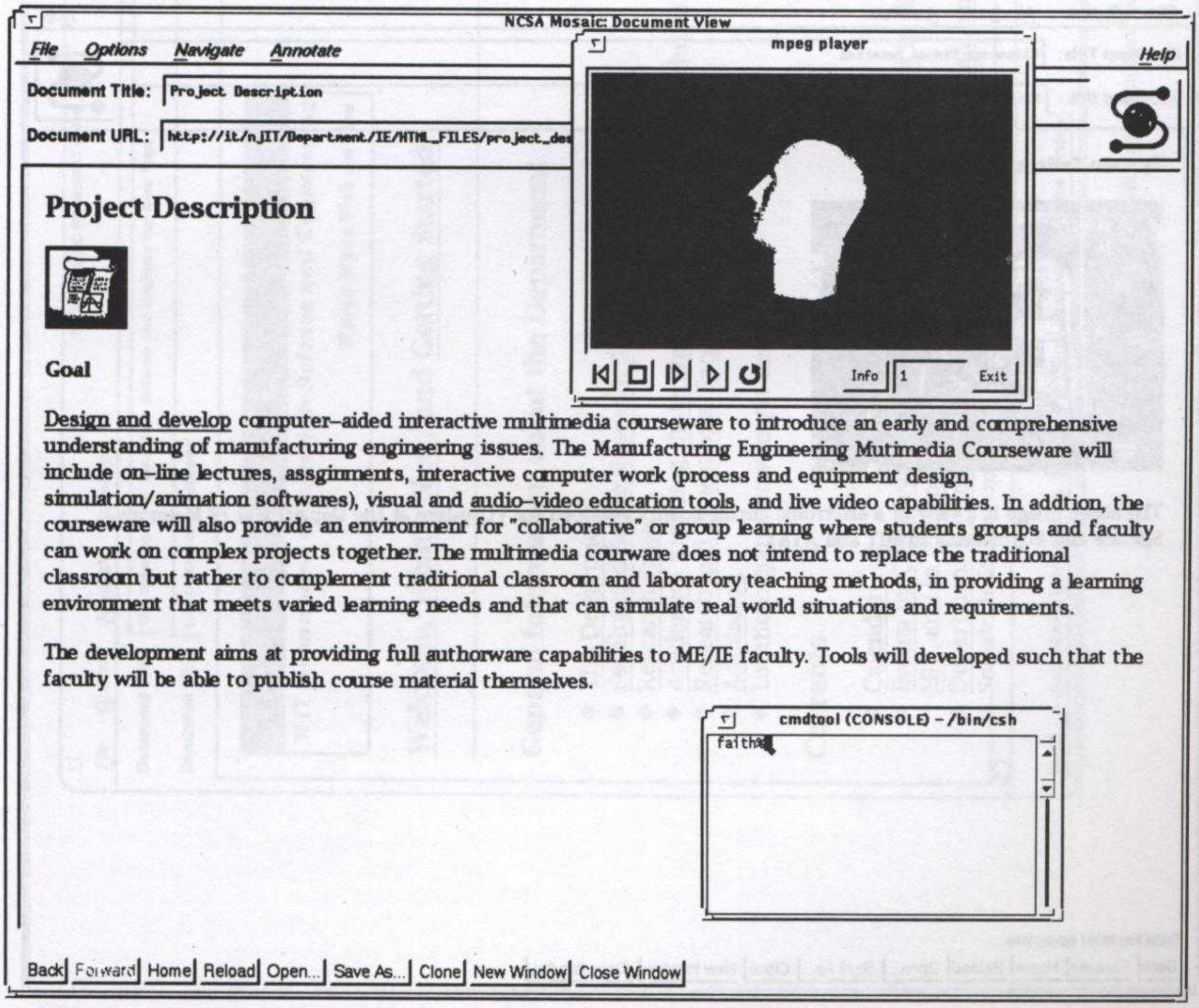

Fig. 3. Demo of accessing project description.

highlighted text 'audio-video' in Fig. 3. Such an interactive document with hyperlinks is also referred to as *hypertext*.

An advantage of using hypertext is that it is possible to cross-reference material at a remote site over the Internet [7]. Simple inclusion of a reference such as http://addresss/filename provides the option of viewing even a multimedia object. It is possible, for example, to move from document to document across the network seamlessly within the same application using various Internet resources such as Gopher, WAIS (Wide Area Information Servers), WWW (World Wide Web) and FTP (File Transfer Protocol) [8]. Figures 5 and 6 illustrate how students can use the aforementioned Internet resources to peruse research material in remote sites, such as the Massachusetts Institute of Technology and AT&T.

Such access to other university, government and industry databases is particularly important, as new technologies are developed at an ever-increasing pace, to keep the students informed of the latest advances. Hence the course material featured in the courseware contains cross-references that either access local information or access information globally over the Internet, for example using the WWW. To access a WWW document, one can use an Internet connection and a client program such as Lynx or Mosaic that runs on Macintoshes, PCs and Unix operating systems.

3.1.2 Factory floor /interactive software. The 'factory floor' consists of tutorials and associated interactive computer programs that illustrate the machines at either the institute factory floor or at remote sites. These tutorials will be comprehensive, providing: an explanation of the machine components, an on-line technical manual for operating the machine, an introduction to the associated manufacturing engineering principles, and an interactive simulation of the machine's operation with several examples.

An interactive tutorial on machining in use in Ohio University [9] has revealed the potential of simulation as an excellent form of computer-based instruction. Just as people do not learn how to drive from reading a car's manual, students cannot learn important skills and procedures by merely reading

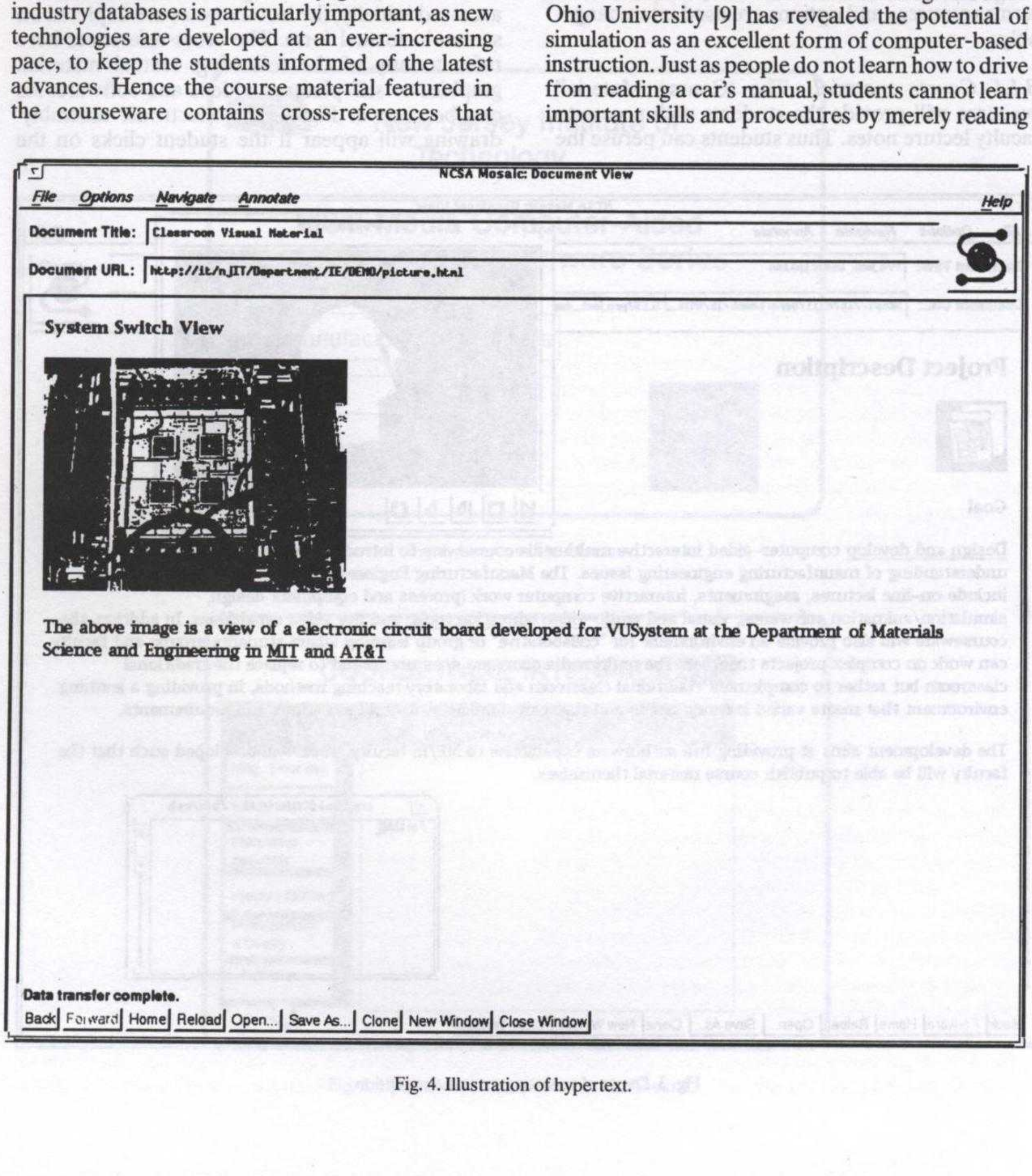

Fig. 4. Illustration of hypertext.

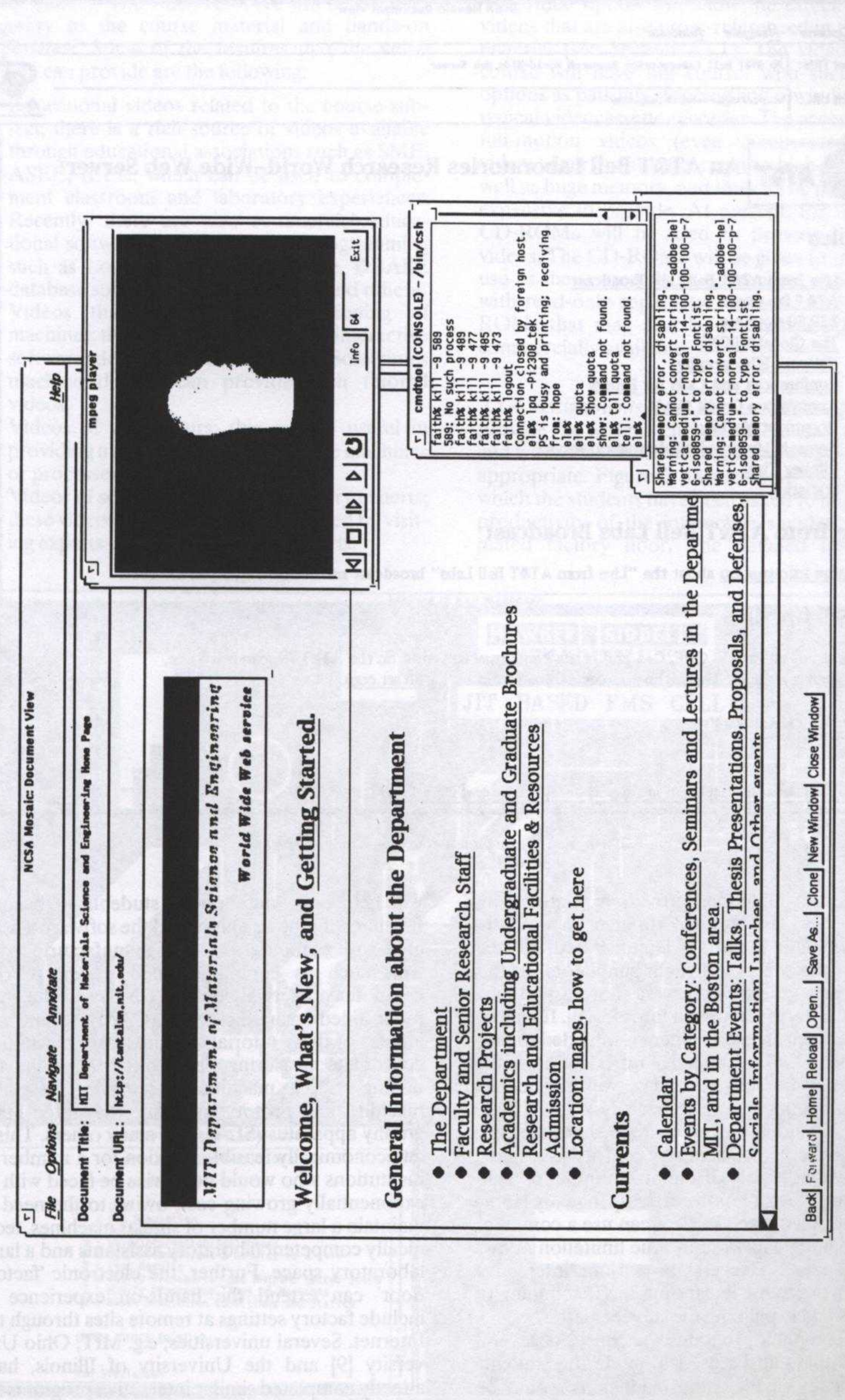

Fig. 5. Illustration of using Internet to access university resources.

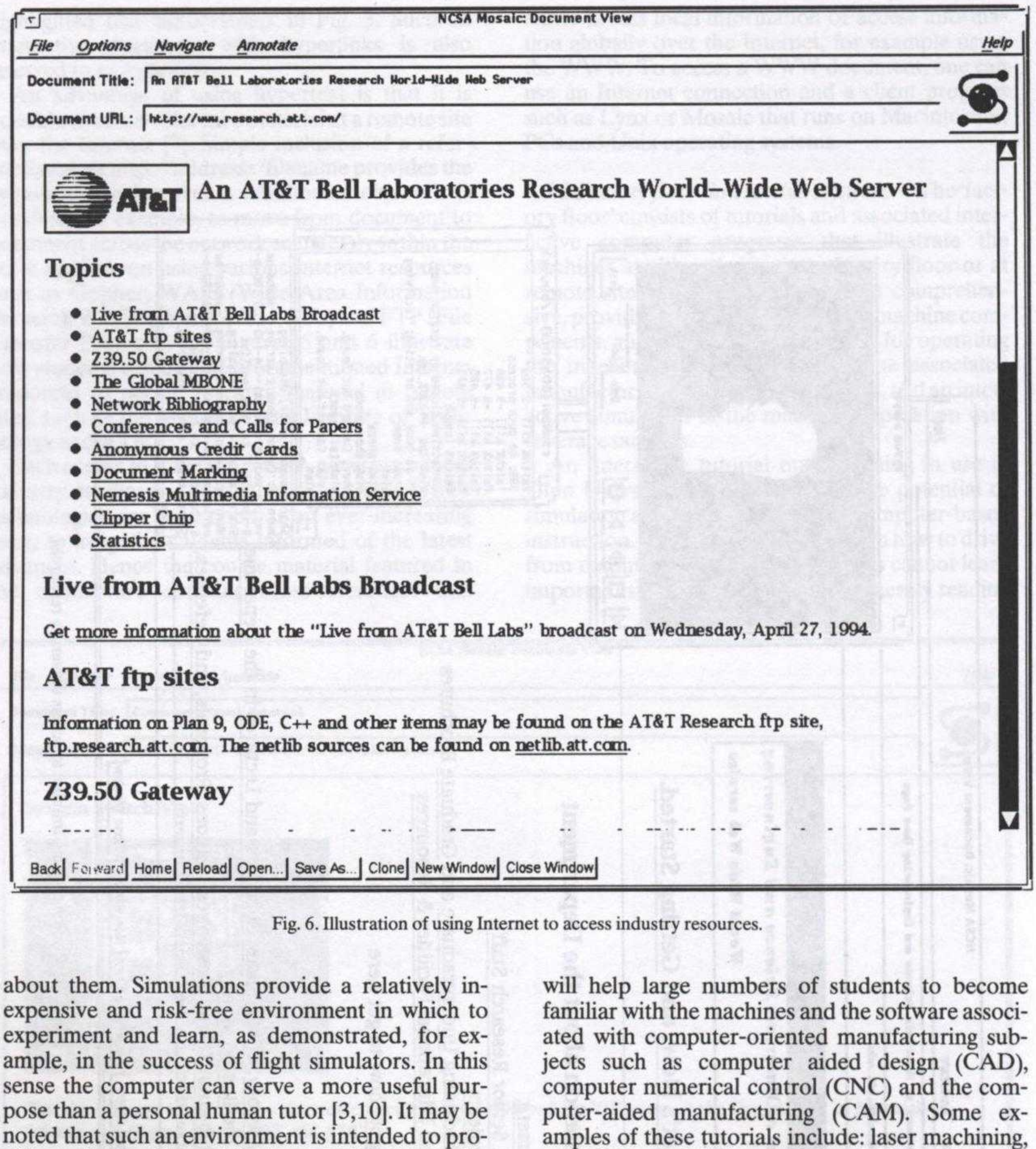

Fig. 6. Illustration of using Internet to access industry resources.

about them. Simulations provide a relatively inexpensive and risk-free environment in which to experiment and learn, as demonstrated, for example, in the success of flight simulators. In this sense the computer can serve a more useful purpose than a personal human tutor [3,10]. It may be noted that such an environment is intended to provide students with an effective introduction to the basics. The interactive tutorials will provide an efficient learning system, especially when a large number of students need to time-share a single expensive piece of machinery and its associated manuals with the help of a limited number of technicians (as is the situation currently in many laboratories). Instead, each student can use a computer independently, and without time limitation at his/her own pace, to access the various interactive computer programs illustrating the functioning of machines and explaining the subject matter.

These computer programs will consist of several examples that can be used to guide the students systematically in the same manner as would be done in real life by laboratory assistants trying to introduce the machines to students. These tutorials will help large numbers of students to become familiar with the machines and the software associated with computer-oriented manufacturing subjects such as computer aided design (CAD), computer numerical control (CNC) and the computer-aided manufacturing (CAM). Some examples of these tutorials include: laser machining, coordinate measuring machine (CMM), lathe and milling CNC machine, electronics assembly machine, and prototyping using the stereo lithography apparatus (SLA), and many others. This is an economically feasible solution for a number of institutions who would otherwise be faced with an exponentially growing cost, owing to the need to maintain a large number of similar machines, technically competent laboratory assistants and a large laboratory space. Further, the electronic 'factory floor' can extend the hands-on experience to include factory settings at remote sites through the Internet. Several universities, e.g. MIT, Ohio University [9] and the University of Illinois, have already completed similar interactive programs for their factory floor and are working on making these available over the WWW.

3.1.3 Video. The video resource will be complementary to the course material and hands-on experience. Some of the features that the video option can provide are the following:

1. Educational videos related to the course subject; there is a rich source of videos available through educational associations such as SME, ASEE, IEEE, which can be used to complement classroom and laboratory experiences. Recently, there are also commercial educational software in basic software programming such as Lotus spreadsheet software, DBASE database software, wordprocessors and others.
2. Videos that illustrate the functioning of machines; these videos can be part of interactive software described in Section 2. Sometimes machine dealers can provide such tutorial videos.
3. Videos of plant tours; this can be useful in providing a real-world context for the machines or processes that are being studied.
4. Videos of seminars offered by industry experts; these videos can be of seminars offered by visiting experts or lectures by other experts.

The video option will allow the direct access to videos that are also cross-referenced in the course material (see Section 3.1.1). The videos for the course will have full control with such viewing options as pausing, stopping and rewinding, as in a typical videocassette recorder. The accessibility of full-motion videos (even compressed MPEG videos) over the Internet requires high-bandwith as well as huge memory, and this can be prohibitively expensive to provide. At present, for this study, CD-ROMs will be used to provide the longer videos. The CD-ROMs will be given to students to use as they currently use computer diskettes but with read-only capability. Many educational CD-ROMs that may also be relevant are becoming commercially available.

3.1.4 Assignments and exams. This option will provide the assignments as well as exams on-line and will be made active at specific time intervals as appropriate. Figure 7 illustrates an assignment in which the students have been asked to improve the productivity of the interactive simulated or animated factory floor. The detailed information

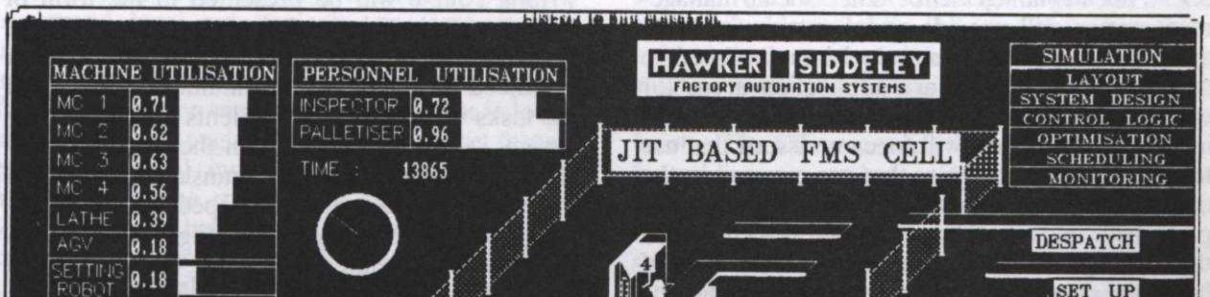

Fig. 7. Manufacturing system design assignment.

about the development and use of interactive simulated or animated manufacturing systems design for engineering education has been explained in detail in ref. [3].

It is possible to administer exams electronically through the courseware. The students can access the exams from a location of their choice and submit their answers electronically during a specified time interval. This type of examination is analogous to the take-home exams which students have to turn in at a specific time and can answer at their own choice of location. A basic advantage of the on-line exams is that the responses can be submitted concurrently to more than one faculty, e.g. to an engineering instructor and to an English instructor to evaluate the exam along different dimensions. This is not very practical in a classical teaching system. The on-line approach will also provide the opportunity for the appropriate topics to be used as part of distance learning courses delivered by the institute. Some of the aforementioned ideas have been developed and field tested, as part of the 'Virtual Classroom Project', at the New Jersey Institute of Technology [11–16].

3.1.5 Social/management. The social/management option will provide social, economic, managerial and even environmental issues related to real-life problems that are application areas for engineering. Although these issues are very general in nature, this option will focus on issues that are targeted to specific topics that are covered in the courseware. The aim of this option is to give a comprehensive understanding of a topic. It is envisaged that this option will be designed with the help of humanities, social science and management faculty. Consider, for example, the design of a large-scale manufacturing system. Simulation and animation will be used to illustrate the design principles and the dynamics of the system [3]. Typically this is learnt by students as part of the engineering curriculum. With the social/management option the students can also be introduced to social, ethical, environmental and business aspects of the system design, as well as the nature of the organization responsible for the manufacturing system.

3.1.6 Communication and writing skills. The communication and writing skill options will include examples and suggestions in writing essays, projects, theses and even exams. This option will be specific to the assignments and include general suggestions and guidelines. From a practical standpoint, it is well known that the ability of students to perform well as engineers in industry depends to a great extent on their communication and writing skills. On the other hand, such skill development is often assumed or paid scant attention to.

Many technologies and products are now too complex to be mastered by individuals working alone. To compete in today's marketplace, a team of skilled people is needed. When projects involve large amounts of finance or large numbers of people, consideration of multiple viewpoints from multiple inputs may improve the chances of success. This approach to organizational work therefore places communication at the center of the action. Further, as international economic competition escalates, the need for transferring technological information and new ideas quickly arises. As instructors of technical writing know, effective communication is the key to effective technology transfer. Since the demand for technology transfer is quickly increasing, engineering education must search for effective and efficient ways of improving communication skills, e.g. use of computers [6,17,18].

It is hoped that making the communication and writing skill options available on-line will help in motivating students to apply, as well as strengthen the effectiveness of, technical writing courses. This communication option will be used by the core courses (identified in Section 4) in the integration of the courseware in to the curriculum. The project presentations, project write-ups and assignments associated with these courses will be supported by introducing related communication and writing skills and samples. The contents of the technical writing course will be presented in the form of numerous tasks to be performed by students. These tasks or assignments will help students to master advanced techniques of communication. Some of the tasks will require the students to discover the design, i.e. experimenting with the strategies professional writers use to translate specialized material for audiences of non-specialists, emphasizing students' thinking powers. Figure 8 illustrates the standard format adopted for presentation of these tasks [17,18].

3.1.7 Help/FAQ. The FAQ option provides help on frequently asked questions. Answers to such questions are compiled over time as students begin to use the courseware. Another help facility will also provide the student with general information about the faculty such as office hours, phone or e-mail to contact faculty, their expertise, and the courses they have taught as well as are currently teaching. It can also contain instructions on searching for information using on-line libraries and over the Internet. All this will help increase access to sources of information and minimize the time spent in having basic questions answered. It will therefore enhance the effectiveness of students.

4. SYSTEM INTEGRATION

By system integration we mean the internal integration of topics within the courseware and external integration of the courseware into the curriculum.

4.1 Integration of topics

Courseware is not just software that features a number of topics chosen by expert faculty; it repre-

Form Attributes	Comments
1. Background	*Introduction of subject matter.*
2. Task Description	*Definition of the task.*
3. Strategies	*Techniques to accomplish the task.*
4. Review Criteria	*Standards to judge the task.*
5. Exhibits	*Samples of task write-up.*
6. Further Reading	*Helpful key readings in subject matter.*

Courtesy of Professors N. Elliot and R. Lynch.

Fig. 8. Illustration of the format used in presenting tasks in technical writing

sents a new teaching and learning paradigm that stresses the synergy among the engineering disciplines. As noted in earlier sections, such synergy is vital to develop a comprehensive understanding of MP&S. Hence, it is important to integrate the topics within the courseware.

The MP&S topics featured in the courseware will be integrated using examples of real engineering applications. Such examples can be from computer, automobile, telecommunication, consumer electronics or any other industry. At the New Jersey Institute of Technology we plan to develop these examples from industry with university directions, and local industry who are part of the university–industry partnership referred to as the 'co-op program'. In this program, students spend their summers or a semester as apprentices in local industry. Since engineering students are future employees, local industry is usually willing to accommodate the students. In addition, the university can use help from industry to bring the curriculum closer to reality [6].

More specifically, the topics within the courseware will be integrated using assignments, projects, hands-on experience and field trips based on examples from industry; for example, if the automobile industry is chosen, then the synergy between MP&S topics such as metal removal, manufacturing assembly and quality control are readily apparent in the production process. In fact, it is possible to organize the integration of topics using a collection of examples around the product development lifecycle, from concept to design and then to production (see Fig. 9). These examples not only serve to integrate the MP&S topics but also to integrate the courseware into the curriculum, which is described next.

4.2 Integration of courseware into the curriculum

It is envisaged that the courseware will be incorporated in the first year (two semesters) of the undergraduate engineering curriculum. This integration will involve four core courses: humanities and social sciences (HSS), computer and information science (CIS), fundamentals of engineering design (FED) and manufacturing processes and systems (MP&S). These courses are not of specific interest here but their role in the overall integration of the courseware will be described.

Consider the product development lifecycle shown in Fig. 10. The product development begins with market analysis and specification of the goals such as the expected cost, functionality, quality, etc. These issues can be covered by the HSS course using specific industry examples. In fact, in the first semester the HSS course can cover general issues such as the history of the industry (the automobile industry in the example introduced earlier), market study, management, social and environmental factors together with the management science faculty. The CIS course, on the other hand, can use forecasting or market analysis or cost analysis examples to introduce the necessary computer tools to students. This includes, for example, spreadsheets and databases. The FED course can introduce the design concepts and principles and how to design the product to meet the functionality and customer requirements as well as production system requirements such as design for manufacturability (DFM). The manufacturing systems and processes that are relevant in the production of the product can then be taught using the courseware in the MP&S course. Within MP&S, as men-

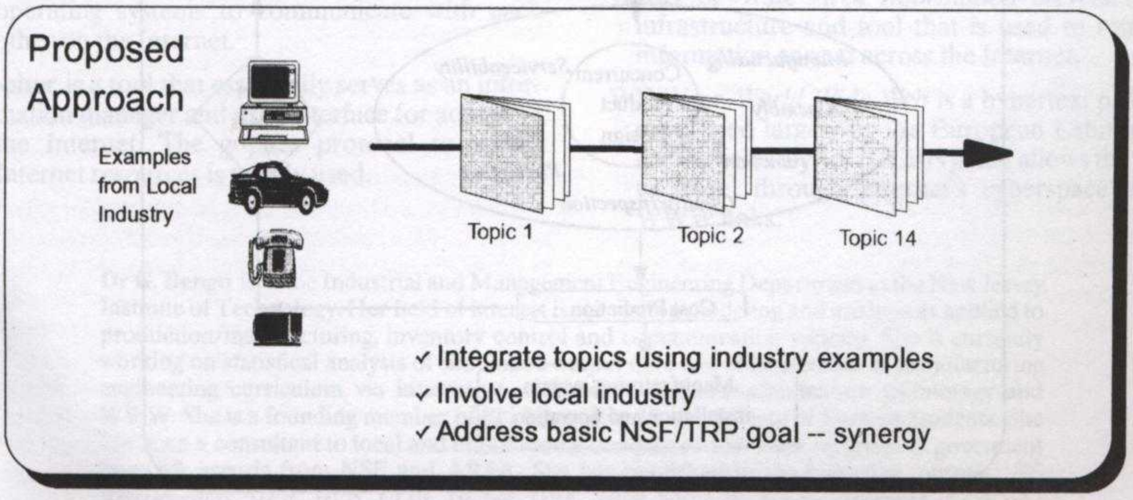

Fig. 9. Integration of topics.

tioned before, the courseware will integrate the topics using examples. The courseware can also be expanded to include the other courses.

Such a parallel curriculum where courses are designed to highlight the synergy in the subjects taught to students is the ideal environment for the use of the courseware. Even the design of the courseware can be beneficial in bringing the faculty together and providing a forum for innovating new ways of teaching and learning. Moreover, the on-line availability of course material helps in introducing faculty to other subjects with less effort. Some of the other advantages of the courseware are

1. A single unified interface provides the students easy and seamless access to the course content and the various interactive options. Due to hyperlink capabilities, the execution procedures become completely transparent to the students.
2. Extensive and comprehensive on-line documentation of the courseware with text and video provides a mechanism to 'standardize' the course by maintaining its integrity regardless of faculty changes, which is much desired but difficult to achieve.
3. The availability of the courseware on the Internet makes it ideal for distance learning, which is a growing trend in engineering education. This is also very important for students who participate in the co-op program (see Section 4.1) and wish to use distance learning to stay abreast.

5. SUMMARY AND CONCLUSION

This study takes advantage of the latest in both computer and information technology to enhance the delivery of education through an interactive, computer-aided teaching and learning tool. It is envisaged that this system will be used to introduce an early understanding of manufacturing issues. A framework for the courseware is developed. Effective use of the new teaching and learning tools requires innovation from faculty to explain issues in various media as well as to provide hands-on experiences. The tool must be viewed as complementary to classroom teaching and a support mechanism to illustrate interdisciplinary issues of engineering applications. It empowers faculty to present vast amounts of information on actual systems to students in a progressive and self-paced manner.

A shift in classroom teaching and learning from a didactic to a more active mode will take time, as teachers will need to learn new strategies, formulate a new conception of knowledge and learning, and develop new habits of classroom response to ensure that students ask questions freely and express opinions and communicate. On the basis of the NJIT faculty experience in using computers, i.e. e-mail for communication among faculty and students, it has been observed that students are more inclined to ask questions than in a traditional classroom environment. Such an environment also permits students easier access to faculty.

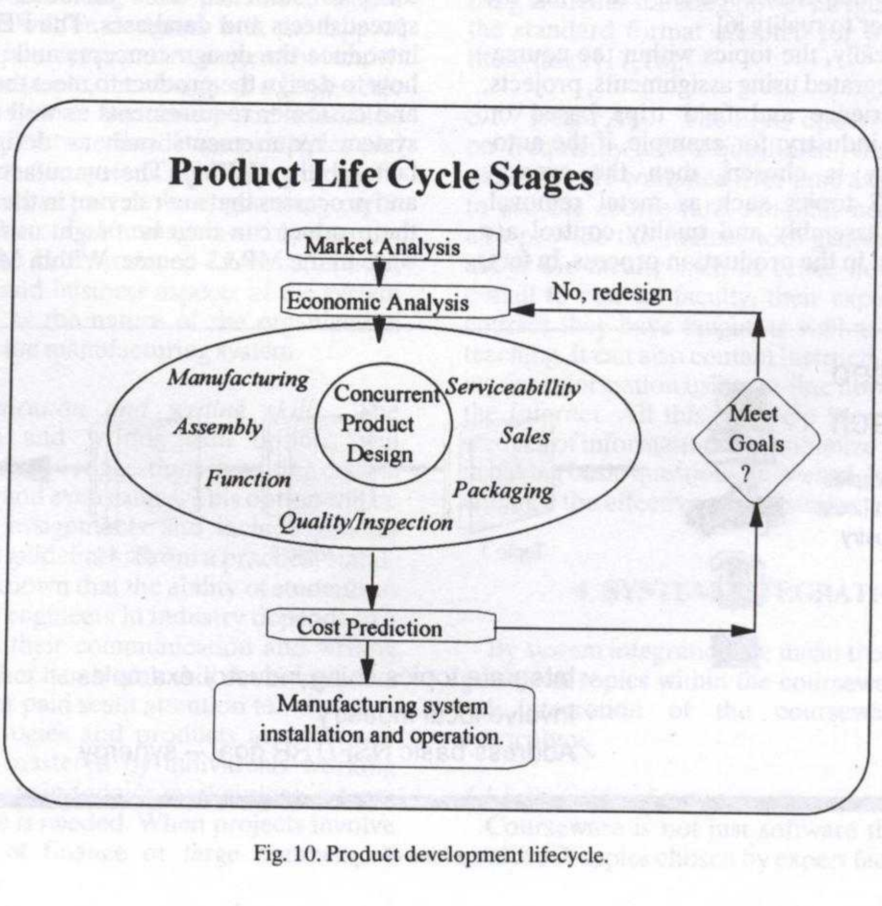

Fig. 10. Product development lifecycle.

The next step in the effort is to develop the courseware based on the design described in this paper. This will be shared with other universities, industry and government agencies.

Acknowledgements—The author would like to thank Professor Norbert Elliot for his valuable suggestions, Professor Ernest Geskin for his encouragement, Professor Eugene Gordon for his support, the other team members and the CCCC group for their cooperation and programming supports.

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APPENDIX: GLOSSARY

FTP or *File Transfer Protocol* is a way of sending files between computers. It is one of the common set of tools that allow computers using different operating systems to communicate with each other on the Internet.

Gopher is a tool that essentially serves as an information manager and user interface for accessing the Internet. The gopher protocol to access Internet resources is widely used.

Internet is a world-wide inter-network of computer networks connected through so-called gateways and held together by a common protocol referred to as TCP/IP.

WAIS or *Wide Area Information Servers* is an infrastructure and tool that is used to retrieve information spread across the Internet.

WWW or *World Wide Web* is a hypertext project, developed largely by the European Laboratory for Particle Physics (CERN), that allows the user to travel through Internet's cyberspace using WWW links.

Dr G. Bengu is in the Industrial and Management Engineering Department at the New Jersey Institute of Technology. Her field of interest is simulation modeling and analysis as applied to production/manufacturing, inventory control and communication systems. She is currently working on statistical analysis of simulation output data and enhancement of manufacturing engineering curriculum via interactive multimedia, simulation/animation technology and WWW. She is a founding member of Phi Sigma Eta, Honor Society of Foreign Students. She has been a consultant to local and international companies and is the recipient of goverment research awards from NSF and ARPA. She has published in the following journals: *IIE Transactions*, *IJPR*, *IJCS*, *COR*, *IJCIM*, *IJEE*, *IJCE* and *CIE*. She is a member of ORSA/TIMS, IIE, Alpha Pi Mu, and Tau Beta Pi.