Kinematics for Manufacturing Engineering Technologists

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Abstract

This paper describes the development of a new computer-based course in Kinematics and Dynamics of Machines, designed for students pursuing BS degrees in Manufacturing Engineering Technology. The course development was based on the premise that basic science and engineering principles are best understood by demonstrating their practical applications. This was the foundation for the detailed learning objectives used throughout the course. The course was divided into modules, each of which first introduces candidates to observable practical applications of kinematics in a manufacturing setting. After these practical examples are investigated, students extend their learning to the more theoretical and analytical concepts. The complete curriculum has been implemented in computer based multimedia form, allowing for individualized self-paced learning. This includes numerous animations and simulations that allow the student to interact with the computer, ask "what if" questions, and get perspectives that would be difficult to show in the absence of a computer. The course also includes a computer-based simulation project integrating the concepts covered in the earlier modules. The first delivery of this course is planned for Fall 1999.

I. Introduction

The traditional kinematics course at a typical American university or college is aimed at mechanical engineering students whose primary interest is design. If not properly structured for the non-mechanical engineering major, it can be a very intimidating experience that discourages learning by the student. In addition to the material itself being intellectually demanding, it is frequently taught in a lecture format with little opportunity for active student participation or experimentation. Consequently, students often find it difficult to make the connection between the theoretical concepts covered in the lectures and the corresponding physical phenomena. This paper describes the development of a course in the kinematics and dynamics of machines, aimed at students pursuing BS degrees in Manufacturing Engineering Technology. The course is being developed under the auspices of the Greenfield Coalition.

The Coalition for New Manufacturing Education, also called the Greenfield Coalition; is made up of Focus:Hope's Center for Advanced Technologies (CAT) - a leading-edge manufacturing and education facility in Detroit; academic partners Wayne State University, Lawrence Technological University, Lehigh University, University of Michigan, and University of Detroit Mercy; as well as industrial partners Chrysler, Ford, General Motors, Detroit Diesel and Cincinnati Milacron; and the Society of Manufacturing Engineers. The goal of the Coalition is to develop a new approach to the education of technicians, technologists and engineers working in the manufacturing field. The CAT is the primary delivery site for the curriculum. In this innovative educational model, selected full-time employees working at the CAT (called candidates) are given the opportunity to pursue degrees in Manufacturing Engineering or Manufacturing Engineering Technology. Taking appropriate on-site courses is a requirement of having 'candidate' status at the CAT. The educational experience at the CAT provides candidates with a diverse technological education integrating the manufacturing resources available on the shop floor into an applications-based engineering education.

The Coalition's overall educational model entails hands-on training in the programming, operation, maintenance, and repair of manufacturing equipment; interdisciplinary study of pertinent mathematics, science, engineering, business, and general education courses; as well as structuring and delivery of knowledge within a production environment to provide context. Another goal of the Coalition is to expand the learning experience to include teamwork, case studies, and hands-on activities. The idea is not that the instructor will disappear from the picture, but that his role will change from a lecturer to a coach. The curriculum is being developed in a modular fashion, making it possible to use a mix of sub-discipline experts to design and deliver modules within a given knowledge area. The proposed curriculum will stress applications as the basis for understanding theoretical concepts. Examples of applications in the candidates' daily experience on the shop floor at Focus:HOPE will serve as the basic motivation to drive knowledge acquisition.

II. Course Development

Special care was needed in the development of this course because the candidates taking the course come from a manufacturing rather than a mechanical engineering background. In order to accomplish the educational objectives of the Greenfield Coalition to learn and understand technical subjects from candidates' shop floor experience, we have conducted the following activities to develop this kinematic course.

1. Undertook an intensive immersion in the functions and activities of the candidates on the shop floor at the CAT equivalent to a full two weeks. This familiarized developers with the typical manufacturing roles and assignments of candidates.
2. Identified relevant shop floor applications at the CAT to be used for launching the learning activities undertaken in each module.
3. Defined detailed learning and performance objectives for each module in consultation with the Coalition's instructional designers and multimedia developers.
4. Identified the core resource (textbook) for candidates to use together with the modules developed.
5. Undertook detailed design of the content and presentation of individual modules in consultation with the Coalition's instructional designers and multimedia developers.
6. Developed appropriate detailed knowledge content for use in each module as given in the description of modules.
7. Developed animations and simulations as appropriate to each module, to demonstrate applications of kinematics and encourage candidates to experiment with pertinent variables on the computer.
8. Liaised with the Coalition's instructional designers and multimedia developers in implementing the modules.

The first half of this course deals with "kinematics" which is the study of the relative motion of mechanism components. The last half of this knowledge area deals with "dynamics" which is the study of the action of forces on mechanism components and the motions resulting from these forces. By completing this knowledge area, students are able to develop scientific thinking rather than intuitive thinking to cope with practical manufacturing issues and problems such as input-output speed control, selection of mechanical components for motion control, positioning error, backlash, dynamic shock, and wear of machine components. For example, a candidate may have the responsibility of setting up a robotic parts-handling system integrated with a machine tool in the CAT manufacturing environment. Although he may not be the one to actually design the system and he might use a machine vendor to build it, his scientific knowledge obtained from this course such as degrees-of-freedom and forward/inverse kinematic analysis will significantly help him to write the required system specifications. After writing the specifications, he can continue to work with the machine vendor through various stages of the system development until the system is successfully implemented in a production environment.

This three-credit course is composed of the seven modules shown in Table 1. The first four modules are considered to be Part 1: Kinematics. The remaining modules (Modules 5 - 7) are considered to be Part 2: Dynamics. As kinematics is the basis for dynamics, it is essential for a candidate to have a full understanding of Part 1 contents before proceeding into Part 2. These seven modules are also grouped into three Greenfield one-credit courses GCF 321 (Modules 1 and 2), GCF 322 (Modules 3 and 4), and GCF 323 (Modules 5, 6, and 7).

Table 1: Modular structure of the kinematics course

Module No.	Greenfield Course No.	Title of Module	Major Topics Covered In Module
1	GCF 321	Basic Concepts of Kinematics	Basic terminology and concepts, Types of joints, Degrees of freedom, Types of mechanisms, Grashof criteria
2	GCF 321	Position, velocity and Acceleration Analysis of Mechanisms	Constructing kinematic models of mechanisms using vectors, Forward and inverse kinematic analysis of Telesis robot
3	GCF 322	Cam Design	Constructing SVAJ diagrams, Synthesizing cams using SVAJ diagrams
4	GCF 322	Gear Trains	Types of Gears, Calculating input-output speed ratios of simple and compound gear trains, Planetary gear systems
5	GCF 323	Dynamics	D'Alembert's principle, Calculation of joint forces and torques of the Telesis robot
6	GCF 323	Balancing	Single plane static and dynamic balancing, Two-plane static and dynamic balancing, balancing system for a 4-cylinder inline engine
7	GCF 323	Final Project	Features of Working Model, Creating planar mechanisms for simulation, Simulation of created mechanisms.

Module 1 covers fundamental concepts of kinematics necessary for pursuing machine design and analysis. A videotape will be used to show practical kinematics applications observed from the manufacturing environment at Focus:HOPE CAT Center. In Module 2, the mathematical approach of analyzing displacement, velocity, and acceleration of simple linkage mechanisms is studied using Focus:HOPE's Telesis two-link robot as a model.

While linkage-type mechanisms are mainly considered in Modules 1 and 2, two other important kinematic elements, cams and gears, are fully examined in Modules 3 and 4, respectively. In Module 3, sample cam applications are shown first. Then several cam motion curves commonly used in industry are studied for their displacement, velocity, and acceleration characteristics. Construction of cam profiles based on these motion curves is also studied, using appropriate CAD software packages. Cam design and manufacturing issues are presented as well. In Module 4, the basic construction and functions of a three-speed gear box used in a drill press at the CAT is examined using the maintenance manual. Then many different types of gears and gear trains are studied and compared, considering practical kinematic applications.

Module 5 is the first module of Part 2: Dynamics. The Telesis two-link robot whose kinematics characteristics were analyzed in Module 2 are studied again, but this time to understand what input torques are required to drive it and what level of pin joint forces exist. Balancing of rotating machinery is one of the most important and practical design/manufacturing considerations, especially in the automobile industry. It is the aim of Module 6 to fully understand the theories behind the operation of the pulley balancing machine at the CAT and to extend them to analyzing the shaking force/torque balancing of more complicated mechanisms, such as internal combustion engines.

Module 7 is the final project of this kinematics course. In this module, each candidate is expected to demonstrate his or her proficiency in the technical materials covered in the previous modules. Candidate will learn how to use basic features of Working Model [jon98, mor98] software and construct simple planar mechanisms, The validity of created mechanisms will then be examined through simulations under given kinematic and dynamic requirements.

III. Examples of Instructional Materials

Module 1 of this course gives an introductory overview of the subject of kinematics. In this module, students learn the terminology, definitions and basic concepts used in kinematics. These are the essential foundation on which understanding of the applications of kinematics in manufacturing are built. On completing the module, students are expected to be able to:

- Define key terms used in the context of kinematics
- Identify the basic mechanism components such as links and joints
- Determine degrees of freedom of selected mechanisms
- Identify and classify different types of mechanisms
- Apply the Grashof criteria in analyzing mechanisms

To accomplish this goal, the module starts with definitions of key terms used in kinematics. In this definition process, the power of the computer is exploited by presenting digitized videos from the CAT shop floor or animations and simulations developed in Working Model to demonstrate the concept being defined. An extended video tour of the CAT facility then follows again using digitized videos of the manufacturing facility with emphasis on kinematic applications. This naturally leads into classification of mechanism components, their purpose in a mechanism, and the students being able to identify those components.

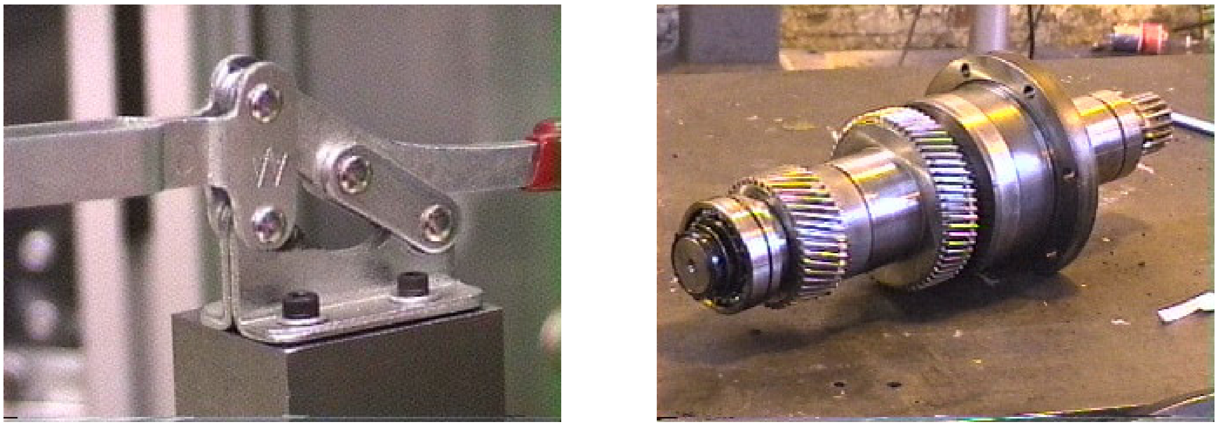

Figure 1: Clamp Mechanism and Gear Assembly Encountered In CAT Video Tour

Determining the motions possible for a given mechanism is an important aspect of kinematics. This is first introduced through the idea of degrees of freedom. The different types of contact possible at a joint are explained. Animations of those joints and the resulting joint motions have been developed in Working Model. When a complete mechanism made up of several links and joints is considered, Gruebler's equation for determining the degrees of freedom of a mechanism is introduced. On the computer, students work with simulations of simple mechanisms and get to determine their degrees of freedom by applying Gruebler's equation. This is then related to actual mechanisms that the students have encountered in their video tour of the CAT facility. This is important in helping the students make the connection between the theoretical concepts being discussed and their practical applications. Specific mechanisms of particular practical interest are then discussed and Grashof s criteria for classifying mechanisms are introduced.

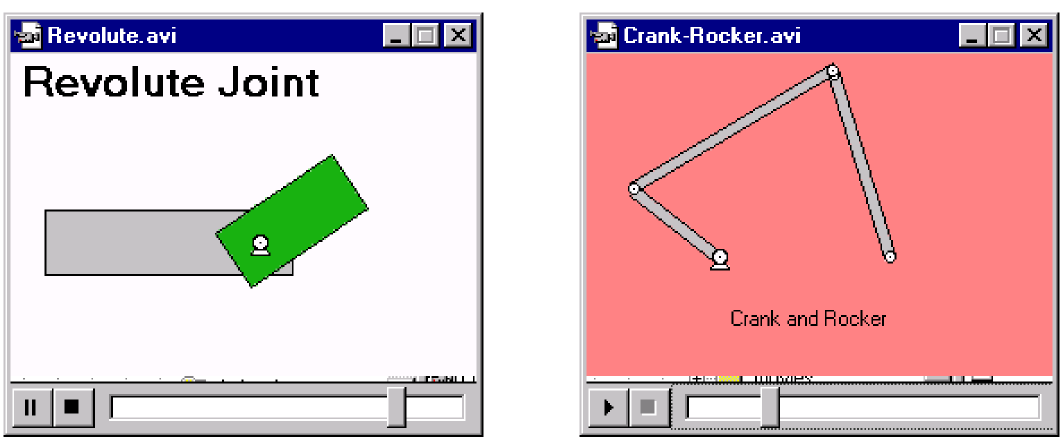

Figure 2: Animations of a Revolute Joint and a Mechanism Utilizing It

Module 2 of this course covers forward and inverse kinematics of a two-link Telesis robot used for pin-stamping date codes on pulleys manufactured at the CAT. The knowledge obtained from this module can be extended to analyze linkage mechanisms in general using vectors.

Candidates first watch a digitized video clip of how the Telesis robot is used in the CAT. The video clip also explains how the kinematics analysis they will study later in this module plays a role in controlling the actual motion of the robot. The three screen-shots shown in Figure 3 are taken from the computer animation to show how a mechanism (in this case the Telesis robot) is converted into a kinematic model using vectors. The animation starts with a still picture from the video clip mentioned above. Then that still picture is converted into the screen shown in Figure 3(a). Objects surrounding the robot (workbench, human hands and pulleys) are removed as the animation progresses and the vector kinematic model is shown with the robot body (Figure 3(b)). Finally the picture of the robot body is removed and the vector model used for the mathematical analysis is displayed (Figure 3(c)). This visual presentation gives candidates a clear process of how a mechanism can be converted into a vector kinematic model.

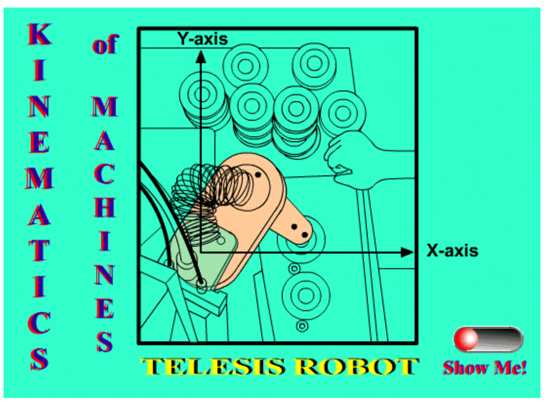

Figure 3 (a): Telesis Robot In Operation

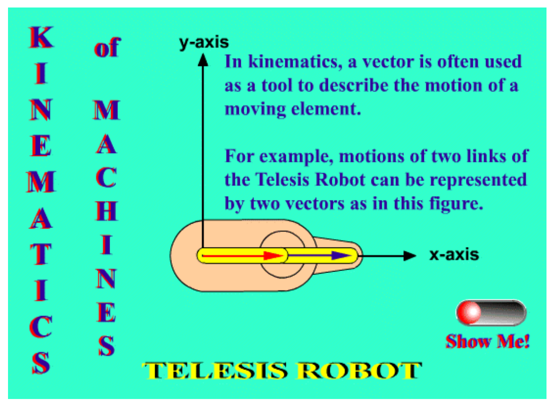

Figure 3 (b): Telesis Robot and Its Vector model

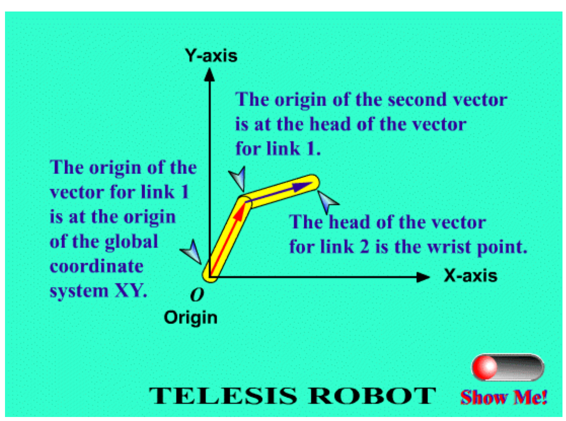

Figure 3 (c): Kinematic Model of Telesis Robot

Candidates will learn the mathematical analysis through computer-based instruction (CBI) screens with the format shown in Figure 4. Most of the CBI screens are designed to be interactive to foster candidates' active involvement in the leaning process. For example, Figure 4 shows a typical drag and drop exercise. Candidates click and drag one of the mathematical expressions provided at the lower right part of the screen and try to drop it into the appropriate gray box area[1]. If the answer is correct it will stay in the box, otherwise it will float back to the area where the expression was originally located.

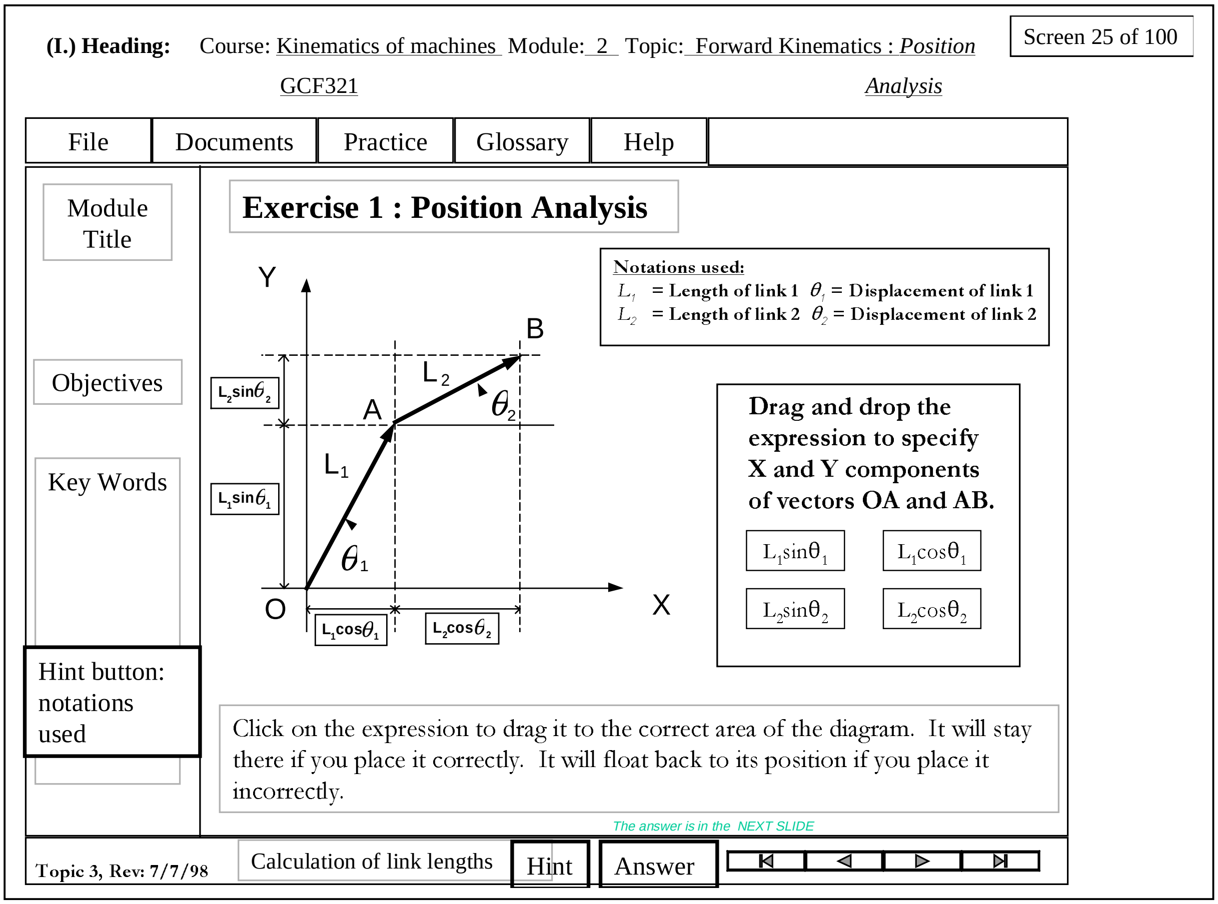

Figure 4: Example of CBI Screen Showing a Drag and Drop Exercise

Computer simulations using Working Model are also used to demonstrate the technical issues covered in the CBI by generating simulated tasks. The computer screen shown in Figure 5 is from a simulation to apply forward kinematics to draw the workspace boundary of a two-link robot. Candidates can examine how the workspace changes by varying the two link lengths and also check if given objects are within the workspace created.

[1] In the field of robotics, the Denavit-Hartenburg [Den 55] conversion is used more frequently to specify joint displacements. D-H conversion is beyond the scope of this introductory kinematics course.

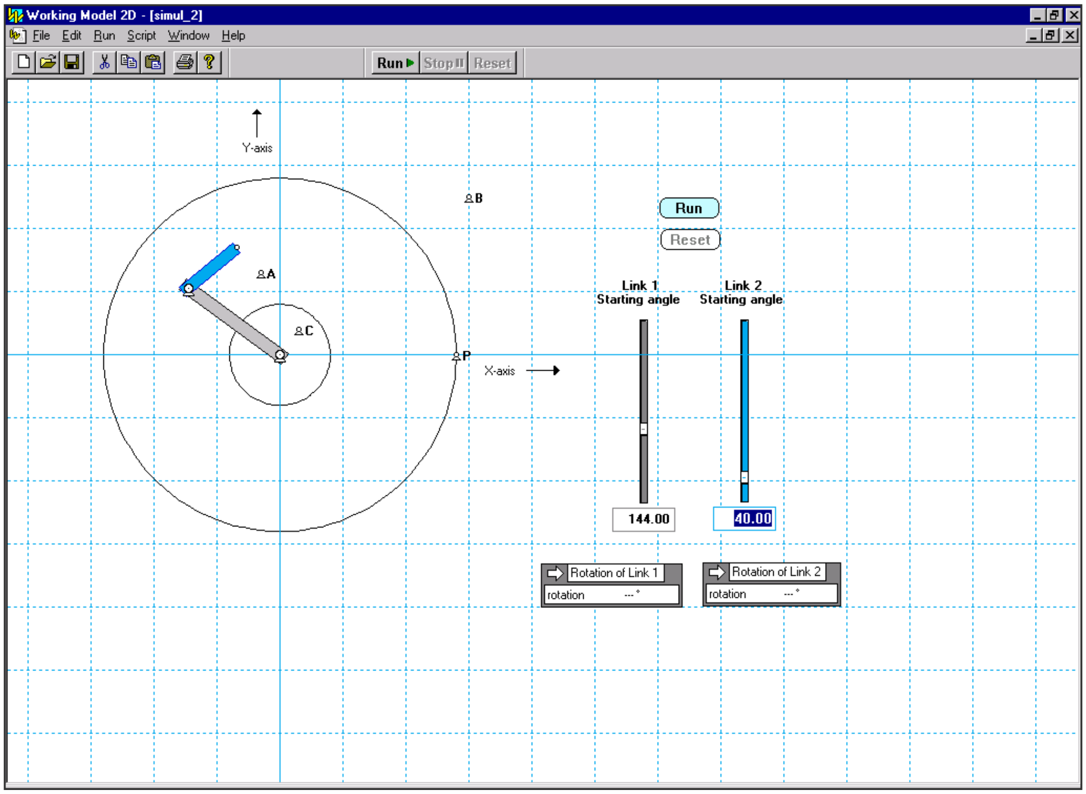

Figure 5: Computer Simulation of Workspace of a 2-Link Robot

IV. Conclusions

Computer Based Instruction is an important new technology that will continue to transform how knowledge at all levels of education is delivered to students. The Kinematics of Machines course described in this paper exploits the power of the computer to enable students to learn in ways that would be difficult to accomplish otherwise. Digitized videos, animations and simulations enable the student to visualize concepts in multiple ways. Additionally, interactive examples and exercises help the student to explore the course content more thoroughly. The first delivery of this course is planned for Fall 1999. At that time a critique from students will be available and will be used to improve the course as necessary. Although initially developed for a specific cohort of working students (and consequently focusing on their work setting), the philosophy employed is easily adaptable for students in other settings. The power of the computer and use of interactive multimedia is expected to make this an engaging learning experience for the students.

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