A Configurable E-Learning System for Industrial Engineering*

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A generic interactive multimedia e-learning system (IMELS) for industrial engineering that uses a problem-based learning approach is developed. The system is designed to be a learning shell with an open architecture for the hosting and delivery of knowledge, case problems and other web-based material in industrial engineering. This problem-based e-learning system is designed to revitalize the teaching/learning process of industrial engineering and to create a learning platform that overcomes the boundaries of space and time. A number of configurable modules are introduced, including a multimedia introduction to industrial engineering, an electronics knowledgebase, and a platform that facilitates interactive problem-based learning through realistic case problems. As the principal objectives of the system are to use the computer-based materials with conventional teaching, and as an up-to-date repository for practitioners in the field, an architecture that accommodates flexible re-configuration, building-up of new information and updating existing materials is provided. This paper presents the design of the IMELS with special focuses on the architecture of the 'virtual company' that supports the problem-based learning paradigm, facilitates dynamic reconfiguration and tracking of student learning activities.

INTRODUCTION

THE ESSENCE of industrial engineering concerns 'the design, improvement and installation of integrated systems of people, materials, equipment and energy' [1]. The discipline draws upon specialized knowledge and skills in the mathematics, physical and social sciences, together with the principles and methods of engineering to specify, predict, improve and evaluate the results to be obtained from such systems. Specialists from various disciplines will be involved in the development of a real-world system and it is the industrial engineer's role to coordinate and manage the integration of these specialist activities to provide an effective and efficient operation. Industrial engineers thus act as the interface between the specialists and the users of the final system. The study of industrial engineering is therefore unique in providing an integrated perspective of how the different engineering disciplines coordinate their activities in developing any practical system, whether it is a service, business or engineering system.

With such a diversie nature of industrial engineering, the teaching and learning of the discipline is deemed to be most effective if students can be introduced to the wide spectrum of engineering principles and be exposed to real-life problems so as to gain experience and to innovate workable solutions. A teaching development project is undertaken by the Department of Industrial and Manufacturing Systems Engineering at the University of Hong Kong to design and produce a generic multimedia teaching and learning system (IMELS) for industrial engineering using the prevailing computer and Internet technology to enhance the effectiveness of the learning process.

While the main objective is to facilitate teaching and learning in the discipline using a problem-based approach, the design of the system must be able to offer the following features:

1. The IMELS is generic such that the computer-based material is able to integrate seamlessly with the existing curricula. The content and resource developed will also be used to support the teaching of courses in the department such as for developing multimedia lectures, laboratory sessions and tutorials either in place of, or complementary to, existing material.
2. The system is able to 'grow' with the ever-changing industrial and business arena. The system is reconfigurable without major re-design. Activities such as the addition and withdrawal of information, creation of new case problems, etc. should be catered for.

Focusing on these two essential requirements, the IMELS is designed to be a modular system that consists of reusable modules. In particular, the current version of the system is structured into three main modules:

- *Module one (M1)* gives an introduction and provide learners with an introductory and broadening view in industrial engineering.
- *Module two (M2)* contains online information regarding the 'IE Knowledge Base', which provides resources within industrial engineering.
- *Module three (M3)* consists of case problems

that are presented within the context of two 'virtual companies', one from manufacturing industry and the other from the service industry.

The structure of the system adopts an open architecture and an object-oriented design paradigm. These main modules can be combined and organized into different structures so as to facilitate specific learning paths for different needs. With this design, the IMELS provides a multifaceted and scalable shell for presenting the abstract concepts and material of industrial engineering that will have a significant impact on the industrial engineering discipline. The system offers students with a combination of engineering practice and associated theory in a desirable, interactive, multimedia and problem-based means. Its key strengths lie in the ability to enhance students' motivation and provide an integrated view of industrial engineering practices within a realistic and versatile problem-centered learning environment.

This paper focuses on the design and architectural aspects of the IMELS, which supports, facilitates and enables interactive learning activities. A problem-based learning sequence is presented through a problem-solving case example in a virtual company. Based on the feedback obtained from students' survey and performance assessment outlined in the later sections on using the system, its effectiveness can be studied.

A PROBLEM-BASED E-LEARNING SYSTEM

Problem-based learning in industrial engineering

Problem-solving is the key role of industrial engineers who innovate and effectively apply the wide spectrum of engineering and managerial techniques to produce workable solutions. A successful industrial engineer thinks critically, approaches problems analytically, and is able to link diverse skills to tackle problems. Some of these skills involve the effective deployment of human and natural resources, the ability to integrate appropriate technologies, to maximize productivity, to provide leadership and motivation, and the capability to optimize so as to achieve the best results. The industrial engineer is able to look at the overall picture of a problem and apply these diverse skills to focus on the source of the problem.

To facilitate industrial engineering students to effectively develop these essential skills so that they adopt holistic views, a realistic approach to learning is necessary. An educational methodology which 'emphasizes real-world challenges, higher-order thinking skills, multi-disciplinary learning, independent learning, teamwork and communication skills' via a problem-based environment is considered to be most appropriate and should be created [2]. A shift from using pure content-based teaching to the use of realistic cases and problems is required to create such a learning environment.

Experience gained from deploying problem-based approaches [3–5, 10] proved that it is one of the most practical and effective methods that focuses students to develop their creativeness, critical and analytical thinking towards problem-solving. Problem-based learning is constructivist in approach whereby the students participate actively in their own learning process and construct their own knowledge [6]. In particular, as industrial engineers deal with real problems, our adoption of problem-based learning with the use of real-life case problems reduces the mismatch between what is taught and what is expected in industry, and this is much welcomed by the employers.

Many educational institutions have adopted problem-based learning to complement traditional teaching in various disciplines in recent years. Problem-based learning approach has been widely adopted in the training of medical doctors [5, 7–9] as it encourages students to 'learn how to learn' [10]. This is especially important to present real-world cases in medical training. In fact, industrial engineers can be considered as 'company doctors' who deal with a diverse spectrum of business problems. The teaching of industrial engineering is therefore parallel to the training of medical doctors where the use of a problem-based approach is highly desirable. With this mode of training, we expect to produce industrial engineers to become better thinkers, analysts and problem solvers who are more competitive and competent that fit better with industry and the business world.

As such, the design of the IMELS follows a problem-based approach in presenting the subject matters of industrial engineering through scenarios that occur in a simulated virtual business environment—the 'virtual company'. Within a virtual company, students are confronted with realistic problems and information where they are free to consult and take advice in order to derive solutions in their own accord. In the following sections, the design of the problem-based learning system is further discussed.

Problem-based e-learning

Compare to traditional methods of teaching that emphasize using classroom lectures and demonstrations, information technology (IT) can provide an environment that lifts the restrictions of time and space in knowledge delivery and capture. With the advancement of computing infrastructure and the Internet, the use of IT for teaching and learning, commonly known as e-learning, has vastly increased the flexibility and effectiveness of knowledge delivery. In a typical e-learning system, IT components including computer graphics, animations, multimedia effect, databases, and other Internet applications such as e-mail and chat room facilities are incorporated to create a cyber-platform for learning.

Such a stimulating learning environment engages students into a deeper learning process that can often elicit a high rate of information

retention, and result in a shorter learning time [11]. In addition, such a multimedia education platform can be interactive, which enables the students to control the content and flow of information capturing [12]. The result is that students become active participants in learning and they take control of their learning processes. Furthermore, with the rapid development of the World Wide Web and other online supports such as online databases and peer-to-peer computing [13], a truly flexible multimedia e-learning system can be achieved where students can obtain knowledge any where and any time at their own pleasure.

In commerce, the use of multimedia for information dissemination and employee training has become widely used, especially in management consultancy, banking, insurances, airlines, government agencies, etc. Companies such as IBM, Compaq, Telstra, Morgan Stanley, P&G, Unisys, PeopleSoft, and Dell are heavily involved in deploying e-learning in their training programs. In the academic community, a number of web-based, e-learning platforms have been developed for teaching [14–16]. Some of these systems are designed for;

- general educational purposes that provide online forum and libraries,
- virtual classroom, peer networks [16, 17];
- Internet-based virtual experimental systems and virtual laboratories for complex process study in chemical engineering [9]; control engineering [18];
- computer science [19];
- electrical engineering and electronics [20].

In many cases where e-learning is adopted, very encouraging feedback from both teachers and students are obtained [7, 22, 23].

As the nature of teaching industrial engineering is well suited for e-learning from foregoing discussions, we developed a multimedia, web-based, interactive e-learning system (the IMELS) that provides a learner-oriented and problem-based learning environment for teaching industrial engineering at the University of Hong Kong. The e-learning system is designed to complement our traditional methods of teaching industrial engineering with the incorporation of four key components of problem-based learning [7]. These include:

- *active learning*—through posing questions and seeking answers;
- *integrated learning*—by tackling problems which require a general knowledge across various disciplines;
- *cumulative learning*—by providing problems with increasing complexity;
- *learning for understanding*—to provide time for reflection, feedback and for practicing the skills learned.

The IMELS encompasses the benefits of e-learning discussed in Buch and Sena [21] for the effective delivery of the materials of industrial engineering through a problem-based approach as well as providing a flexible platform to support continual development of the entire teaching system. More specifically, the IMELS is designed to include the following main features:

- The system provides a comprehensive overview of the industrial engineering discipline, an online knowledge base that provides up-to-date references for the topics of industrial engineering, and realistic case problems found in typical manufacturing and service industries for students to resolve.
- The system supports a user configurable environment for teaching industrial engineering. Teachers can configure the teaching material while students can configure their individual learning paths. As such the system is scalable and flexible, and continuous modification and updating are structured and fully guided.
- The system incorporates appropriate IT to enable the content to be presented in an interactive and multimedia format, making use of computer graphics, animations, video, and sounds to enhance the effectiveness and arouse the interest of students. In addition, facilities for launching assignment, tracking students' learning activities, forum and chat room environments are provided.

With this philosophy of designing the IMELS, it is envisaged that the teaching and learning processes will be more efficient and take place in a more acceptable and attractive environment for students and teachers alike. In the following sections, the architectural design and functionality of the system are explained.

SYSTEM ARCHITECTURE

The IMELS system is structured into three distinct modules and with a web-based learning management system. To cater for the flexibility of continuous development and reconfiguration, the system consists of two major parts, namely, a CD-ROM based component and an online component. In particular, the CD-ROM component acts as an easily distributed user interface of the learning system for students whereas the online component acts as the repository for hosting the content of the knowledge base and the case problems. The dual-platform design also provides a vehicle for easy expansion and upgrade. The architecture of the overall learning system and the organization of the major components are given in Fig. 1. Based on this system architecture, the specifications of each of the major components are described in the following subsections.

Introduction to industrial engineering

M1 provides a multimedia introductory presentation of the industrial engineering discipline. The content lays down the key facts about the roles and
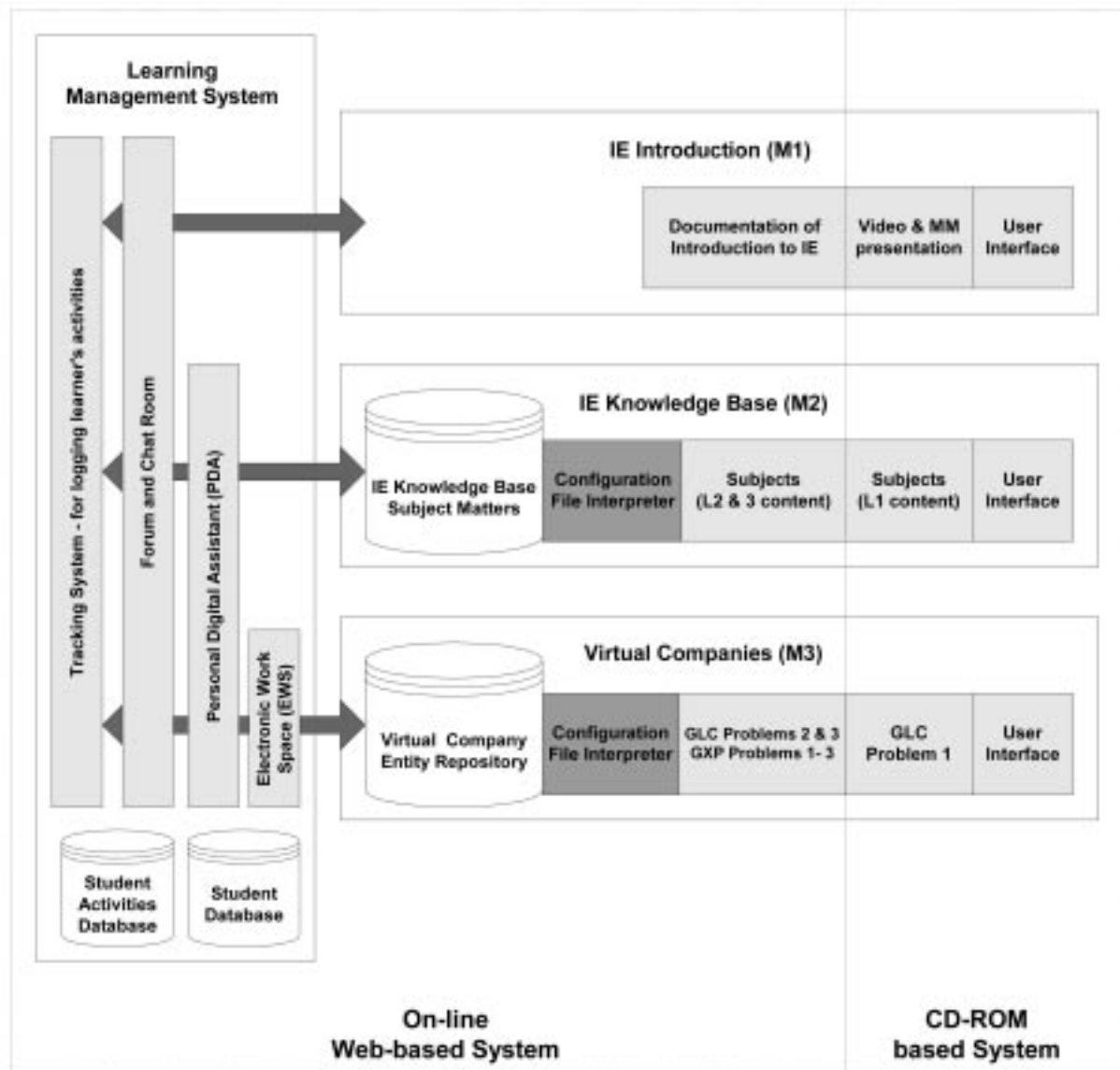
Fig. 1. The architecture of the learning system.

importance of industrial engineers in a visual and dynamic means. The architecture of M1 is such that the material is structured in a modular and reusable format, which consists of:

a) a short introductory video that highlights the different aspects of industrial engineering, the impact and roles play by industrial engineers in our society, the skills of industrial engineers, and the opportunities of industrial engineers; and

b) a multimedia introduction suit that presents various topics of industrial engineering using graphics animation, video clips, voices, and supplementary documents.

IE knowledge base

The IE knowledge base facilitates students to effectively obtain knowledge and subject matters

of industrial engineering while they are engaged in the learning shell. This electronic repository of material is cross-linked and referenced to the case problems that are presented by the virtual companies. Some of these major knowledge areas include ergonomics, product development, production planning and control, supply chain management, simulation, system analysis, quality, maintenance and reliability engineering and project management.

Under each knowledge area, a subject matter is broken down into three levels of understanding. Each higher level goes deeper into the subject matter. At the top level (Level 1), the content is structured to provide an overview of the subject matter with learning objectives and the fundamental concepts clearly stated. In Level 2, an introduction to the guiding principles, models and techniques for is further explained, while
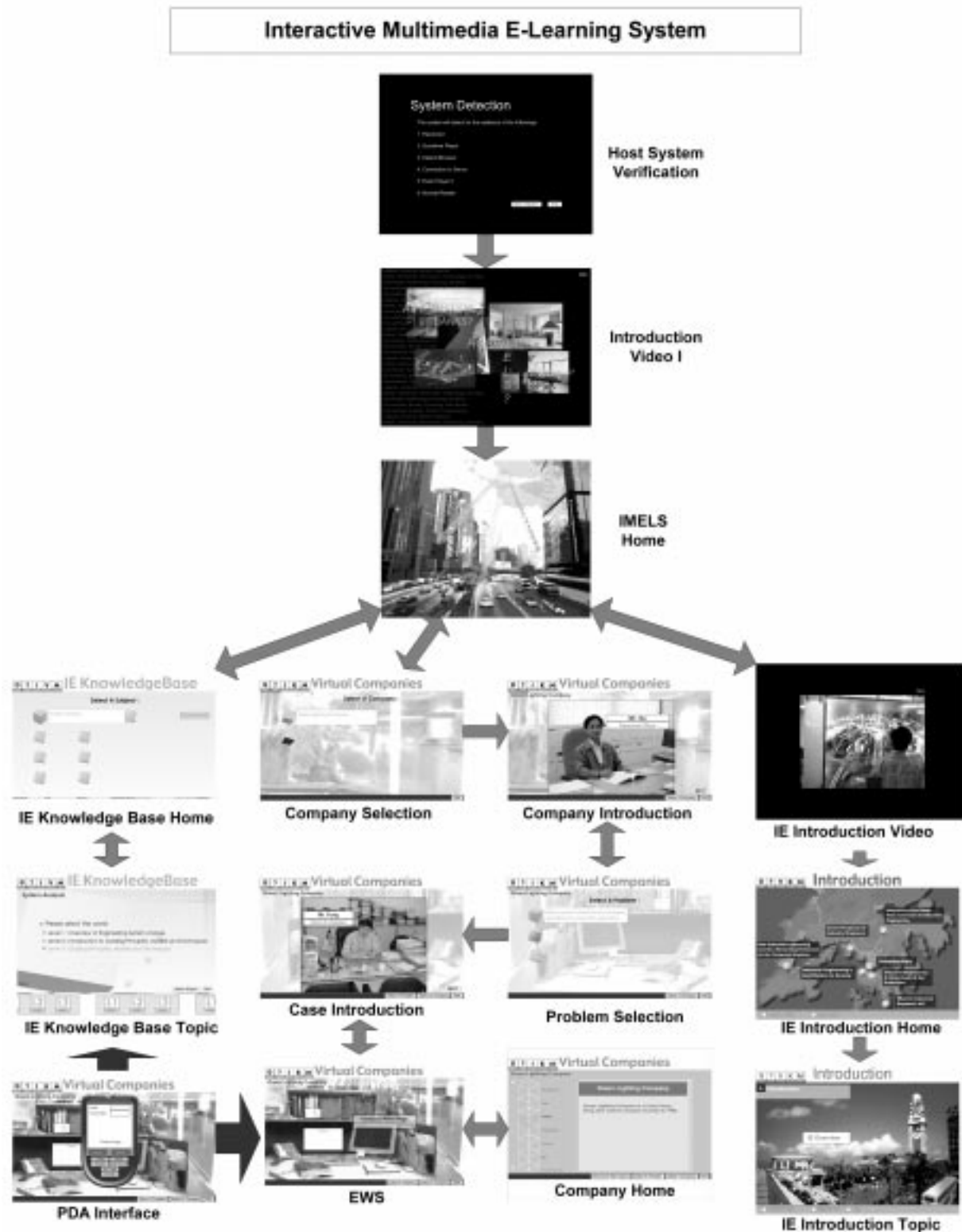
Fig. 2. A road map of the learning system that implements the proposed architecture.

Level 3 contains detailed descriptions and explanations of the guiding principles, the models adopted and the different techniques commonly applied.

The presentation of Level 1 and Level 2 contents are in animated PowerPoint format with voice over whereas Level 3 materials are presented as HTML documents with hyperlinks to web pages, supplementary materials and references for further learning. In addition, some of the subjects may provide simple quizzes at the end of the presentation to enhance students' engagement in the learning process.

As the IMELS is designed to be an open shell with scalability and maintainability, the number of

subject matters, their structures and presentations can be configured via special configuration files. The functionality of the configuration file system is further discussed in the next section.

Virtual companies

The novel concept of a Virtual Company is to represent a hypothetical business enterprise that exists only within the IMELS, which on the other hand, is representative enough to simulate and reflect the operation of a typical real-life business organization. As the central aim of the system is to provide a comprehensive, problem-based learning environment in both the manufacturing and service industries though the use of case problems that may exist in reality, two virtual companies, one representing a manufacturing business—the Green Lighting Company, and the other representing a service industry—the GX Porting Holdings Corporation are included.

The design philosophy and the development of the virtual companies provide a scalable platform that supports the problem-based learning paradigm. Through the provision of interactive multimedia sceneries and dialogues with personnel in a virtual company, a student can undertake a fully learner-directed tour within the company and experience vividly the various scenarios of a selected case problem under one's own navigation. Furthermore, the design of the virtual companies provides a structure and mechanism to dynamically reconfigure the content materials when new case problems and background materials are subsequently introduced. Together with the learning management system, the system provides facilities for tracking the learning activities while students interact with the various entities of the virtual companies in a problem solving exercise.

In order to attain the flexibility of re-configurability and to achieve an open-shell architecture, the design of the Virtual Company is based on an object-oriented paradigm. The platform provides flexibility for the teachers and system managers to update and configure case problems according to the needs of the curriculum. A number of configuration files are used to set up and configure the material of the virtual companies.

The basic building block of a virtual company is called the Business Unit (BU). The BU base-class provides a template whereby specific virtual company objects can be inherited and created. Instants of the object representing different logical business units that are needed to build a virtual company, such as the problem introduction, the different departments in a virtual company, and various sections within a department, are automatically created based on the definitions given in the XML-based configuration files (Appendix A). The tool for creating a BU is based on a macro-engine that is developed as part of the virtual company system. This macro-engine interprets the definitions in the configuration files associated with a case problem, associates the scenarios of the case problem with the web-based repository, and then generates the graphical entities that are displayed through the user interface.

In a typical problem solving session (Fig. 2), a student will be directed by the virtual company system to first select a particular company that has previously configured. An introduction to the company will automatically follow the selection and the student can then select a problem of his/her choice to tackle. After going through an introductory presentation of the selected problem and a tour of the virtual student's workplace, known as the Electronic Work Space or EWS, the student is then free to navigate around the various departments to start tackling the problem. The student can visit and listen to comments and instructions from members in the company through the Voice Over lists (VO lists), using the Personal Digital Assistant (PDA) to make notes, and go through documentations to work out a solution. The logical flow, organization and structure of the virtual company system is defined by the architecture shown in Fig. 3.

According to Fig. 3, the departments in a virtual company are organized in a hierarchical format that can support any number of departmental levels in a company. Each business unit bears a unique ID number and a parent ID number that represents the business unit one level higher than itself. The specific hierarchical structure for each virtual company is generated by the macro-engine based on the ID numbers and their relationships.

The navigation between business units are achieved via an interface that represents the departmental hierarchy in a virtual company. The interface is generic and configurable via specific configuration files that defines the department structure and the associations of content information with the business units. After a student selects a target business unit (department or office) to visit, an animated movie that fills the transition is also provided.

Configuring a virtual company—the configuration file system

One of the main features of the virtual company is configurability of its content information. A macro-based interpreter is developed and incorporated in the virtual company system that enables the company structure to be setup and organized according to a particular case problem. The interface between the interpreter and the actual case problem settings is a set of virtual company configuration files. These configuration files configure a virtual company's scenes, department structure, characters and their associated behaviors, and the associations of system information such as content materials, subject matters, and case supporting documents with business units and graphical entities. System managers and teachers can easily change a specific virtual company structure according to the details of the case problem by
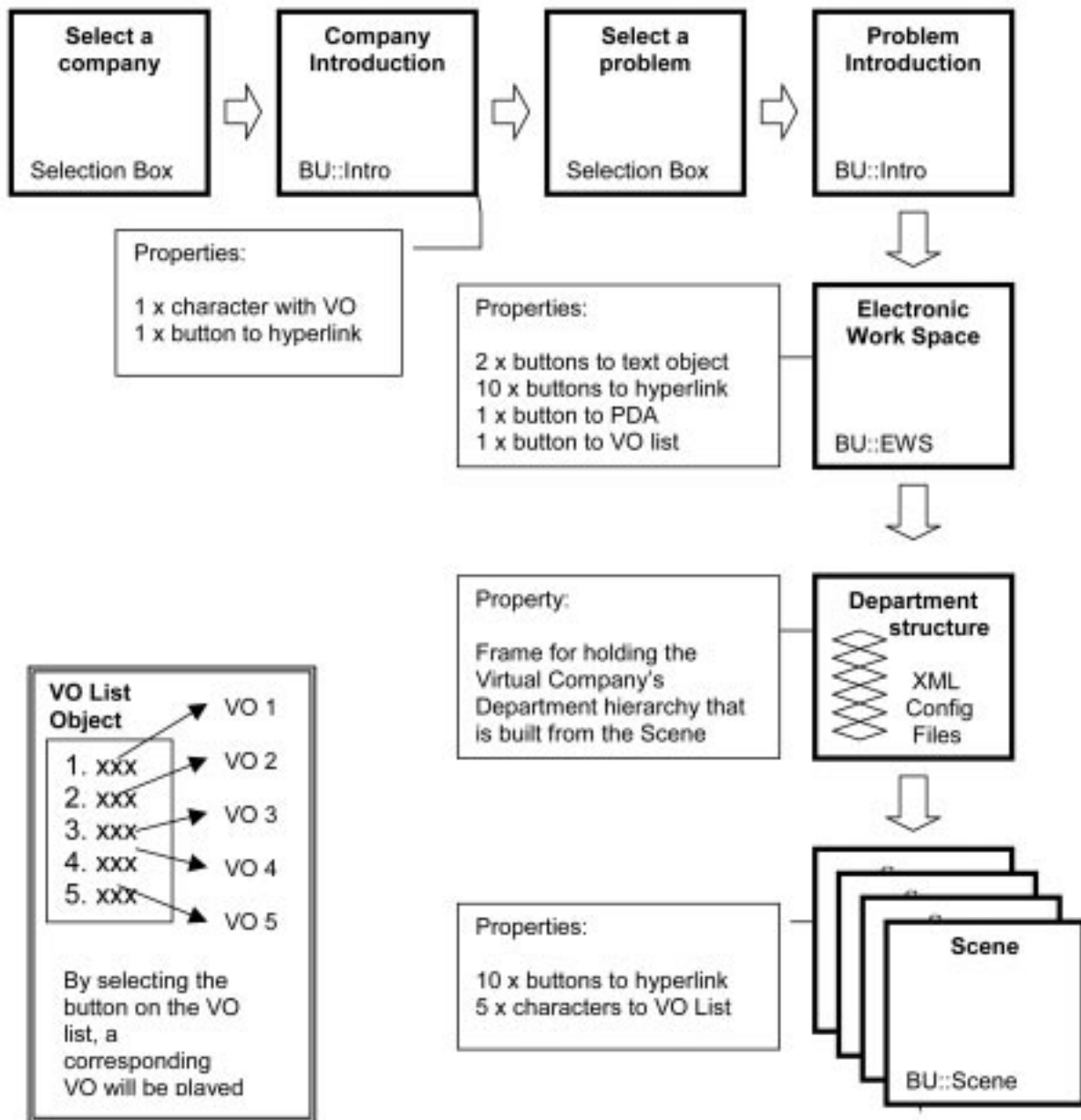
Fig. 3. The architecture of the virtual company.

modifying the entries of the corresponding configuration files written in XML.

The same mechanism for configuring the content material of the IE Knowledge Base (M2) is also introduced. The knowledge base configuration files provide the means to define the number of subject matters to be included, the organization of each level of knowledge, and the linkages between the references and supplementary materials.

The learning management system

In addition to the content material of the IMELS that are included in M1, M2 and M3, a web-based learning management system is also incorporated to facilitate teachers to monitor and track students' activities, enable students to communicate with other participating students, and maintain their individual learning portfolios.

The learning management system has four major components, namely:

- **Electronic work space (EWS).** In a virtual company, a virtual office is provided for each student known as the Electronic Work Space (EWS). This is a virtual desktop environment that contains a number of useful features that facilitate a student to tackle each selected case problem. These features include the Personal Digital Assistant (PDA), a PC terminal that allows the learners to access the company's webpage containing company information, a filing cabinet that contains company's document, a whiteboard that lists the problem objectives, and a telephone that connects the student

Fig. 4. The case problem introductory screen for the GX Port Holdings Corporation.

directly to the Senior IE consultant's office of the virtual company.

- **Personal digital assistant (PDA).** The Personal Digital Assistant (PDA) is the main interface that allows a student to logon to the learning system when online information is requested. The PDA is directly connected to a student database. In addition to maintaining the student's identity while participating in the e-learning process, the PDA provides a media for word editing, documentation of information, online communication with other students and subject experts, and access to the subject matters in the IE Knowledge Base. The PDA is therefore designed to be the main linkage between the Virtual Companies and the IE Knowledge Base where knowledge can be cross-referenced in the problem solving process.

- **Forum and chat room.** An online discussion forum is incorporated where students and teachers are allowed to raise queries while taking part in the e-learning process with the IMELS. To enhance the communication between students, an online chat room is introduced to allow informal information exchange between learners. In addition, the chat room also acts as a platform for pre-scheduled short discussions between students and teachers in an online mode, which is also backed up by an e-mail link to facilitate the submission of assignments.

- **Tracking system.** The tracking system enables teachers and system managers of the IMELS to monitor and analyze the learning activities while the students are using the system. The system produces log files for tracking the learning activities through logging the interactions made by students with the various entities in the IMELS. The tracking system is designed to track activities including: hit count for accessing web-based materials, downloading of materials, using the forum and chat room facilities, submitting assignments, responding to queries raised by

Fig. 5. The virtual company web page that can be called up from the e-induction button.

Fig. 6. The IE Consultant.

teachers, and accessing the entities within a virtual company during the problem solving exercise. In addition, the tracking system provides customized reporting facilities where data captured are organized and exported to other spreadsheet applications for subsequent analysis. Using these reports and data, information such as the effectiveness of learning, time spent by students in various parts of the system, dropout rate, and completion status of students can be derived and studied.

IMPLEMENTATION OF THE VIRTUAL COMPANIES—THE GX PORT HOLDINGS CORPORATION

To illustrate the design and operation of the Virtual Company, a typical problem solving process is illustrated with the GX Port Holdings Corporation. The GX Port Holdings Corporation is a virtual company that represents a typical logistics business. The case problem selected in this illustration is to examine the possible causes of traffic congestion that exists in the gate house of the container port.

A student who enters the Virtual Companies module selects a company and a case problem of their choice according to the system flow (Fig. 2). After a case problem is selected, an introductory page of the company is shown (Fig. 4) from which the student can choose to review the background of the company by going through the e-induction program. Supporting materials in the form of sound tracks and online information (Fig. 5) can be freely assessed. In addition, a description of the problem is given by the Senior IE Consultant of the company (Fig. 6) and the student is then introduced to his own workspace—the EWS (Fig. 7) before he/she is led to explore the various departments in the company (Fig. 8).

In the GX Port Holdings Corporation, a number of departments including the Commercial, Management, Finance, Logistics, Security, and Operations departments including the Gate House and Parking Area are created (Figs 9 and 10). When the student is participating in the interactive problem-solving process, he/she is free to visit any department, to consult the personnel in that department, to listen to the comments given by the employees through the VO lists (Fig. 11),

Fig. 7. The student work space—the EWS.

Fig. 8. Company structure showing the hierarchy of departments in a virtual company.

and to browse available online company document in the form of hypertext and video presentations.

After touring around the various departments and listen to the comments given by various employees concerning the particular problem, the student can consult the IE Knowledge Base; communicate with other students, and teachers through the PDA (Fig. 10). The PDA provides direct access to the topics available from the IE Knowledge Base, and also connects the student to the Forum and Chat Room facilities. In this case, the technique of simulation can be used to student the traffic flow at the gate house, and the situations can then be analyzed based on the simulation results. A solution to the problem can be derived by the students and submitted to the teacher for further discussion.

ASSESSMENT OF THE EFFECTIVENESS OF THE SYSTEM

An assessment plan was formulated to study the impacts and effectiveness of the IMELS to the teaching of industrial engineering, and to enhance students learning and understanding of the subject matters. The assessment consists of two parts, namely, a series of evaluation exercises through focused-groups, and the actual deployment of the system in courses that are offered by the Department of Industrial and Manufacturing Systems Engineering in the fall and spring semesters 2002—2003. As the system adopts a problem-based learning approach, the assessment also focused on the successfulness in enabling students to learn how to learn.

Fig. 9. A scenery in the GX Port Holdings Corporation.

Fig. 10. A department scene showing the character, his workspace, and the PDA that can be called up by the student.

Specifically, the means of assessment for the actual deployment of the system include:

- Questionnaire surveys
- Classroom observations
- Performance on assignment
- Individual and small group discussions with students

For the focused group evaluation, groups of students, industrialists and education professionals were invited to evaluate the package. For the student focused-groups, in addition to students selected from our department, students from other institutions, some of those who are not studying industrial engineering were also invited. A questionnaire was used to elicit their views on the design and usability of the system. For the focused group evaluation, in-depth discussion was also held at the end of the exercise to consolidate the feedback from using the system. Members of the groups were asked to voice their opinions and put forward their suggestions on improving the system with regards to the content material and design, presentation, use of computer-based technology, and the authenticity of the case problems. In addition, group members are also encouraged to propose means to enhance the effectiveness of using the system to amalgamate with the existing undergraduate teaching approach.

In addition to the focused group evaluation, the system was used in two undergraduate courses offered by the department, namely, the Engineering System Analysis course and the Engineering Project Management course. In the Engineering

Fig. 11. A VO list showing the various comments given by the character.

System Analysis course, 24 students enrolled in the course and the case problem—the development of a system model of the production operation of the Green Lighting Company—was used. The students use the system in an individual basis and an assignment is collected after three weeks of using the system. For the Engineering Project Management course, 94 students enrolled in the course and they were grouped into 47 groups. In this course, the case problem concerning the preparation of a project plan was used. The students worked in pairs, and each group was required to produce a project plan as the assignment.

In both cases, the participation in the questionnaire surveys was on a voluntary basis, and anonymity was maintained for the responses. In addition to student surveys, small group discussions were also held while the system is being used in class, at the end of the exercise, and after the teachers had reviewed the student assignments. The results from the various means of assessment, including the performance on assignments were used to evaluate the usability and effectiveness of the system as a self-directed e-learning platform.

EVALUATION RESULTS

The results obtained from questionnaire surveys, classroom observations, group discussions and the students' performance at the end-of-exercise assignments are discussed in this section. The questionnaire surveys focused on seven areas concerning the fulfillment of its purposes, consistency; operability, quality and content of the system. Classroom observations were based on teacher observations on student learning behavior, the type of queries they raised and their level of

engagement while they were using the system in classes. Furthermore, group discussions and the performance on assignments enabled teachers to obtain in-depth understanding of the student opinions and experience on using the system.

Questionnaire survey

A questionnaire was designed to objectively seek student opinions on the system in terms of the effectiveness and suitability of the IMELS for e-learning, the overall design such as display features, animation, computer graphics, etc., ease of use, compatibility standards, production quality, instructional design and program functionality. A number of questions were asked in the questionnaire and these are grouped into seven main areas. Altogether, 86 replies were gathered and the distribution of results is shown in Table 1.

According to the results obtained, a very large number of students who had used the system welcomed the introduction of IMELS as an e-learning tool for industrial engineering. The animations and videos helped them to appreciate the more abstract concepts and put more life into the subject matters. In particular, the problems that are presented through the virtual companies very much enhance their understanding of the practical issues that exists in the industries concerned, and the system provides an effective platform to assist them to think, learn and produce solutions to these real-life problems. Furthermore, students favor the use of the web-based and online features such as the EWS, chat room and forum.

As this is the first time the IMELS was launched in our department, technical supports such as the availability of computer terminals, the performance of the web-server and the network bandwidth might not be tuned to their optimal operating conditions. This might in some way

Table 1. Student surveys results

Area	Descriptions	Strongly disagree	Disagree	Agree	Strongly agree
1	Stimulates interest in learning the subject, effectiveness of instructional design, including relationships between course purpose, objectives, instructional content, instructional methods	0.0%	18.4%	68.4%	13.2%
2	Promotes an integrated understanding of industrial engineering that is supported by the features provided by the system including navigation functions, tracking features and other operation supports	2.3%	23.2%	62.8%	4.7%
3	Display feature qualities, including the design of the course map, navigation frame and content frame	4.3%	10.6%	78.7%	6.4%
4	General production qualities, including quality of courseware's text, animation, graphics, grammar and visual presentations in making learning more effective	4.0%	6.0%	76.0%	14.0%
5	System functionality review—adequate human computer interfacing, operation efficiency, customization support, and ease of integration	8.6%	11.4%	62.9%	17.1%
6	Compatibility standards—the system provides effective means for registering demographic information, system configurations and learning preference	6.7%	20.0%	60.0%	13.3%
7	Acceptance of the IMELS as an e-learning courseware for teaching and learning industrial engineering	0.0%	6.0%	86.0%	8.0%

affect the overall performance of the system and this was reflected in the response obtained from groups 2 and 4 in the questionnaire surveys (Table 1). In addition, engineering students in Hong Kong are less accustomed to problem-based learning, and this was also reflected in some of the less positive responses found in the surveys. As a whole the surveys strongly indicated that the IMELS had stimulated and motivated student interests in the subject, and improved their learning performance in the discipline of industrial engineering as a whole.

Classroom observations

From the group discussions with students who used the system, teachers found that the case problems had prompted students to raise better quality questions concerning the subject matter compared to students who are taught in normal classes. The stimulating learning environment provided by the IMELS has engaged students in a deeper learning process that elicited a high rate of information retention, and resulted in a shorter learning time that shown a good depth of understanding of the subject matter. Most of the comments given by the students reinforced the conclusions obtained from the questionnaire surveys.

Discussions with members of focused groups and students

Discussions with the focused group members tended to be more critical towards the content design and effectiveness of the system in facilitating problem-based learning in industrial engineering. The specialist and industrialist groups unanimously felt that the IMELS is a first-of-its-kind e-learning system that was produced for industrial engineering. Its value in promoting the discipline and as a platform for not only university teaching, but also a knowledge portal for practitioners in the field, would be significant. The general impression was that the open-shell architecture adopted will have a great potential in future development and expansion.

In the discussions with students who have used the system, most students strongly felt that the package would provide them with an exciting learning experience in the fundamental areas of industrial engineering. A number of students felt that the introduction of the IMELS was a big step forward for the department in teaching and learning and they suggested that the system should be introduced to all courses in the industrial engineering curricula. In addition, most students commented that the content material reflects good creativity and innovation, with a very interactive interface and the environment can stimulate and enhance their interest in learning the subject matters. Since this is one of the first problem-based e-learning system that was introduced to industrial engineering students in Hong Kong, and as in general, local engineering students are more accustomed to structured and instructional modes of learning, we found that there are students who have taken some time to get used to this learning paradigm. Yet, once they had familiarized with the system and got used to the modes of learning, they very much enjoyed using the system as a means of learning.

Student performance on assignments

In both courses, assignments submitted show that the quality of the work produced has improved, in particular the understanding of the problem when comparing to students who were not introduced to the IMELS in previous years. A majority of students were able to understand the fundamental concepts and principles of the subject matter more quickly, and mastered the techniques and methodologies more competently. In addition, some of their work had reflected depth of understanding where solutions to the problems were produced which were more intuitive and practical.

CONCLUSION

An integrated interactive learning open-shell that incorporates multimedia presentations and web-based technology known as the IMELS is developed and presented. The system adopts a problem-based learning approach to the teaching and learning of industrial engineering. The architecture of the system supports flexible configuration and updating of content materials through the use of XML-based configuration files such that the learning paths can be crafted to suit different needs. The current system incorporated three main modules, namely the IE Introduction, Knowledge Base and Virtual Companies; and a learning management system that provides facilities including the electronic work space, chat rooms, and forums to form a comprehensive e-learning platform.

The principle of the system is to expose students to a learning environment which is seemingly full of complex case problems incorporated in a highly authentic context. This feature is achieved by the design of the virtual company concept where realistic scenarios, personnel, dialogue and documentation organized and presented using computer-animated cyberspace. The functionality and operation of the system is also demonstrated by a brief run-through of a case problem in the virtual GX Port Holdings Corporation. Though the system is designed to be self-contained and autonomous for learning, it provides supports for teachers and subject experts in answering students' queries online and to help them to accomplish their learning objectives. From the positive feedback from the evaluations undertaken, it is found that the system also facilitates the formation of a collaborative learning environment thereby creating learning communities in industrial engineering amongst students.

As the package is designed to be an important part of the teaching material for the industrial engineering curricula at the University of Hong Kong, more courses are planned to use the system as a major teaching aid in the near future. It is envisaged that the introduction of the IMELS will ultimately arouse similar interest among other higher education institutes that teach industrial engineering. It provides a potential linkage between the academia and local secondary schools, as well as the general public in appreciating the industrial engineering profession and its contribution to society. More specifically, the architecture of the system, especially the web-based content, is design to be an open shell, which can be further enhanced to form an information portal for industrial engineering. Practicing industrialists can make use of such a portal to exchange their experiences whereas academics can use the material as realistic case studies in the teaching and learning of the discipline.

Moreover, as more courses in industrial engineering are using the IMELS, we are currently working on the design of enhanced evaluation schemes and upgrading the tracking feature of the system so that the learning activities undertaken by students and the learning behavior of students can be further investigated. Analytical studies of learning efficiency of different batches of students (including B.Eng. and M.Sc. students), effectiveness of problem-based learning for industrial engineering, effectiveness of content material design and their presentation techniques, can then be undertaken.

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