Education Technologies in System Dynamics Teaching

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Abstract: *System dynamics teaching is still predominantly face-to-face and classroom based. Though evidences of distance learning in system dynamics are appearing in the literature, the community as a whole is yet to appreciate and embrace distance learning approach. Distance learning could popularise system dynamics and enable educators to take benefits of the modern education technologies. The modern education technologies have made subject delivery flexible: learning independent of distance and formal teaching timings. This paper presents a critical appraisal of application of modern education technologies in teaching and delivery of system dynamics subject. It is suggested that problem-based learning (PBL) is an appropriate approach for system dynamics teaching, which could be feasible with the help of the Internet, e-mail, CD-ROM, teletutorial, teleconferencing and other education technologies. The design and implementation of a PBL framework is discussed in this paper.*

1. INTRODUCTION

The growth of system dynamics in the last forty years is far from spectacular. System dynamics as a discipline did not spread widely. In fact, the education and research in system dynamics remained localised at various pockets in the UK, USA, EEC and the Third World countries. Only in the recent years some degree of dispersion both worldwide and within individual countries became visible. There could be many reasons for the limited spread of system dynamics. But an important factor is the lack of or limited use of education technologies by system dynamicists in teaching and delivery of the subject matters. The use of modern education technologies could make system dynamics teaching more flexible, the implication of which could be significant in terms of spreading the knowledge of system dynamics.

The teaching of system dynamics is facing two challenges. First, the inability of the conventional teaching method in helping learners to achieve the learning objectives. System dynamics is an area of study where dynamic and complex relationships among various aspects of a system are modelled in a computer and the long term behaviour of the system is analysed. This subject requires students to be trained with a high degree of problem solving ability and visualisation power to discern causal effects in dynamically changing situations. Richmond (1993) suggests the development of seven critical thinking skills (dynamic thinking, closed-loop thinking, generic thinking, structural thinking, operational thinking, continuum thinking, and scientific thinking) in system dynamics studies. Richmond argues that our capacity for thinking in terms of dynamic interdependencies has not grown rapidly to cope with the complexities that is being faced by the mankind. To impart various thinking skills in students and to accomplish various learning objectives it is necessary to expose students to computer model building and system behaviour testing using real world policy alternatives. Conventional system dynamics teaching strategies are unable to create learning experiences that would efficiently facilitate learners to achieve the expected learning outcomes.

Second, increasing demand to course access outside the standard on-campus teaching provision. The need to widen the access to courses and course materials has become a recognised imperative worldwide. Flexible learning is seen as a solution to this imperative (Ferguson and Wong, 1995; Mandal and Ferguson, 1994). It allows courses to be delivered to learners on campus, in the industry, at home or in an enterprise, on a schedule to meet the demands of individuals. With different dimensions of flexibility, this mode of learning increases access for individuals to learn and removes barriers to learning. These barriers exist in the conventional learning mode in the form of inflexible attendance requirements, geographic limitation of teaching location, individual learning difficulties, etc.

The system dynamics community realised the need for flexible delivery of the subject matter only recently. System dynamics course through the Internet in the form of Guided Study Program (GSP) is offered at MIT under the leadership of Jay W. Forrester.[1] The program is for people interested in learning the basic principles of system dynamics and model simulation. The program is a guided study (conducted by e-mail) consisting of study materials from the "Road Maps" series and other system dynamics literature, structured assignments, and feedback on assignments.[2] This program is organised in a very structured way and the teaching strategy used in this program is very different from the problem-based learning strategy advocated by this paper.

There are evidences of other initiatives to make system dynamics learning accessible through the Internet. A computerised network version of the famous 'Beer Game' is now available *via* the Internet. Machuca and Barajas mentioned that 'The use of the Internet allows distance learning to take place, given that the facilitator of the game can not only transmit the results obtained, but can also ask questions and get answers, send explanatory texts for briefing and debriefing, receive questions from the players, etc. Through this type of distance learning, instructors who desire to use the Beer Game as a teaching instrument can be trained, even when they are far away' (Machuca and Barajas, 1997, p. 337). Other information on system dynamics courses around the world is also available at the Web now.[3]

System dynamics teaching is still predominantly classroom based and face-to-face. The system dynamics community as a whole has yet to embrace distance learning as a

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[1] For details of this distance learning initiative visit the Web site at http://sysdyn.mit.edu/DistanceLearning.
[2] Information on “Road Map” can be found at http://sysdyn.mit.edu.
[3] See for example the Web site at http://web.mit.edu/sdg/www/sdg-courses.

means to popularising the subject and taking advantages of the modern education technologies. It is proposed that the modern education technologies would make the delivery of system dynamics flexible and make the learning independent of distance and formal teaching hours.

Based on a funded teaching development project, this paper reports the design and development of a problem-based learning framework for teaching of system dynamics. The teaching model encompasses a non-traditional problem-based interactive learning environment that is Internet supported, student-centred, and can be flexibly accessed by on- and off-campus learners independent of time and geographic location.

2. THEORETICAL BASES OF LEARNING ENVIRONMENT

In recent years university education has undergone through big changes. The forces that exerted important impacts on these changes are:

- the growing competition,
- the explosion of information technology (Peterson, 1997),
- expansion and complexity of knowledge about the natural world,
- increasing international collaboration,
- growing university-industry link in pursuing research of industrial significance (Morgan, Reid and Wulf, 1998), and
- the imperative need to widen the access to education (Wong and Ferguson, 1996).

Graduates are now required not only to possess specific and auxiliary content knowledge but also abilities to identify, formulate, and solve real world problems; communicate effectively; to perform teamwork; and engage in life-long learning (DEETYA, 1996; ASEE, 1994). To inculcate students with these abilities there are calls to use non-conventional teaching methods, which are facilitative rather than authoritiative and foster collaborative active learning (Baillie and Walker, 1998). Flexible and open learning can be viewed as a solution to widen the access to various courses (Wong and Ferguson, 1996; Ranky, 1996).

2.1 Flexible learning

There are three factors that can be used to describe learning. They are ‘learning style’, ‘control’ and ‘focus’. Learning style refers to the way students process the information in the course material. Control refers to the degree to which the student rather than the teacher controls the learning activities and the instructional strategies. Focus refers to the extent to which emphasis is on providing support to student-centred learning as opposed to traditional teacher-centred teaching. These three factors can be used to define a cube on 3-D planes as shown in Figure 1.

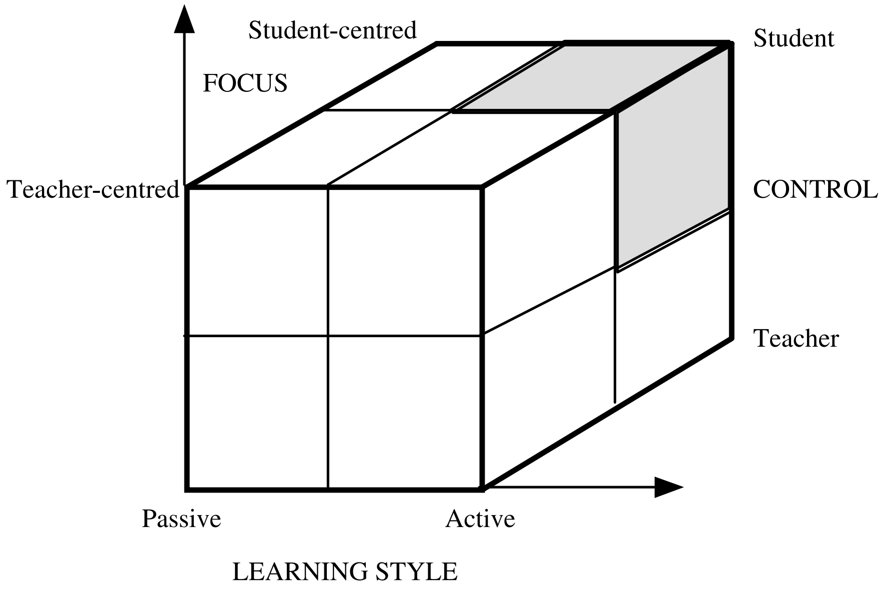


Figure 1. Dimensions of learning

If this cube can be divided into regions, flexible learning finds its position at the right, upper back region as marked in the Figure. Flexible learning enables a series of general shifts along the continua from conventional classroom teaching. Students actively participate in the learning process rather than passively absorb knowledge, have more control over instructional strategies rather than following fixed procedures set by the teacher, and have access to a wide range of supporting resources which are student-centred rather than teacher-based.

Fleming (1993) summarised the practice of flexible learning as ways in organising and resourcing learning that shift away from traditional lecturing and supporting services so as to offer "the learner a more actively constructive role by providing a framework in which learning goals can be more independently pursued" (Fleming, 1993).

2.2 Problem-based learning

Problem-based learning is a very motivating learning strategy that encourages critical thinking and problem-solving skills together with content knowledge by asking students to work out real world problems. Teachers become facilitators to provide resources and guidance to students as they develop content knowledge and problem-solving skills. Students actively take up greater responsibilities for their own learning.

As recognised by Banerjee and De Graaff (1996), an important aspect of problem-based learning is the shift from teaching to learning. In a total problem-based learning situation, the learning process is initiated by a problem. Conventional teaching is replaced by learners' discussion among each other on loosely defined real world case scenarios and to formulate learning goals. Students are encouraged to undertake in-depth analysis of the problem or situation to identify possible subproblems, questions, issues, or trends related to the case scenario. They then begin to investigate these subproblems by using research methods such as interviews, surveys, observations, document analyses, and search through advanced reference materials such as professional journals, indexes, and data bases (Dooley, 1997). In the course of analysing, redefining, and suggesting solutions to the problems, prior knowledge is activated and new knowledge is acquired and learners are undertaking a deep learning process to find answers to their own learning goal by self-directed learning.

Regardless of the specific methodology of problem-based learning applied to different context, there are a number of common characteristic features, *inter alia*, the most significant ones suggested by Williams and Williams (1997) are:

- Collaborative learning – learners must be encouraged to work collaboratively to foster a supportive learning environment.

- Self-directed learning – this can be fostered by allowing learners control over aspects of the learning process such as planning the learning timetable, choosing who to work with, deciding what and how they will learn.

- Reflection on learning – learners should be asked to reflect on the learning process by thinking about their learning experiences as a whole to consider what deficiencies there are and how these may be remedied, whether a learning plan was achieved or how the goals could be more efficiently met.

A typical problem-based learning situation involves groups of students working interdependently and collaboratively, sharing ideas, splitting learning responsibilities, and continuously keeping each other informed.

3. EDUCATION TECHNOLOGIES

Education technology is essentially a 20th century movement with major developments occurring during and immediately after the Second World War. Education technology refers to a particular approach to achieving educational goals. The focus is on systematic development of teaching and learning procedures, which are primarily based on behavioural psychology. In recent years, the fields that contributed greatly in the development of education technologies are cognitive psychology, social psychology, psychometrics, perception psychology, computing and management.

There are a number of technologies that enhances the effectiveness of teaching. The important technologies are the Internet, CD-ROM, e-mail, data-bases, CAL programs, videos, tele-tutorial, videoconferencing, etc.

The Internet

The most distinctive distance education deliver tool is the Internet. The Internet based communication system could use bulletin boards, which could be used by a student to contact his/her lecturer and other students. It allows students to access other resources such as the library catalogue and book request from the library.

Computer aided learning

Computer Aided Learning (CAL) programs use standard high density floppy discs and students can use CAL programs to learn a subject at their own pace. One example of a CAL program at Deakin is an interactive program called 'Ethics' developed for the first year engineering students to help students develop professional ethics. Other CAL programs have been developed to support learning subjects as diverse as workshop practice, electricity, and engineering statics.

Videos/ CD-ROM

Videos and CD-ROMs can be helpful in describing the subject matter. For example, video simulations of laboratory experiments could be developed for off-campus use. Interactive CD-ROMs are very useful as repository of course materials and quick search of information.

Videoconferencing

The use of videoconferencing eliminates the presence of students on the campus. Face-to-face lectures would be progressively replaced by videoconferencing.

Teletutorial

Teletutorial is an alternative to face-to-face tutorials for off-campus students. It involves the tutor and a small group of students connected at the same time by telephone. This has the advantage that students feel less isolated from the university because of geographic separation. Exchange of ideas through teletutorial sessions encourages distance education students to know more about the subject, fellow students and the university as a whole.

The use of Internet technology

Given the success of problem-based learning requires functional supports to enable interaction, allow dataflow, provide access to global and local information, and event monitoring, it is essential to include collaborative learning tools that will provide all these supports. As a tool of Internet technology, the World Wide Web is ideal in providing the necessary supports to problem-based learning for its “ability to create an active learning environment, one which affords the learner opportunities to engage and think. The Web also opens the world in terms of the people who can be reached and the resources that can be gathered” (Hill, 1997).

Stauffer (1996) in researching student-driven learning on the Internet also showed Web-based instruction is useful for intellectual knowledge building. The Web, according to Stauffer (1996), is a delivery medium as well as a provider of content and subject matter. Through this medium, text, graphic, sound and video can be delivered to students easily. Furthermore, the Internet links people world-wide, and contains a highly diverse, easy-to-update source of information.

To address the need for promoting interaction among students and to provide what Johnson-Lenz and Johnson-Lenz (1991) described as open spaces within which students can decide on the types of interaction that took place, a conferencing groupware has to be sought. To facilitate flexible access, this tool should have the capability to allow users to meet synchronously or asynchronously, as appropriate. SoftArc’s icon-driven, user friendly, multi-functional conferencing system was selected for its compatibility with the Web.

4. PBL FRAMEWORK FOR SYSTEM DYNAMICS

System dynamics requires students to be trained with a high degree of problem solving ability and visualisation power to discern causal effects in dynamically changing situations. To accomplish these learning objectives it is necessary to expose students to computer model building and system behaviour testing using real world policy alternatives.

Conventional teaching strategies used in on- and, in particular, off-campus teaching are unable to create learning experiences that would efficiently facilitate students to achieve the expected learning outcomes. In the traditional lecture plus tutorial mode of on-campus teaching, lectures are often "long periods of uninterrupted teacher-centred, expository discourse that relegate students to the role of passive spectator" (Johnson, Johnson and Smith, 1998). Lecturer presumes that "all students need the same information, presented orally, at the same pace, in an impersonal way, and without dialogue with the presenter" (Johnson, Johnson and Smith, 1998).

While in the conventional mode of off-campus teaching, lectures are normally replaced by self-instructional courseware, largely print-based and some with supplementary material in multimedia format. Students study the supplied materials and complete all the course requirements according to a set schedule on their own. Within these conventional modes of teaching, students passively receive information and they can not find sufficient interaction with the study material, teachers, and peers.

Interaction among students, teachers, and the learning environment in the form of collaborative learning is an important factor in facilitating students to acquire live knowledge and develop problem-solving ability. There is a need to create a non-traditional learning environment that adopts interactive teaching strategies, more student-centred, and can be flexibly accessed by on- and off-campus students for teaching of system dynamics. The framework for such a learning environment is presented next.

The focus of the learning environment is on the following aspects:

- To provide flexible access to study by students on campus, at home, or in their workplace independent of time, pace, and learning style;
- To provide students with interactive learning experiences;
- To enable students to develop problem-solving ability;
- To assist students to acquire real-world knowledge; and
- To enhance students' communication skills.

Figure 2 shows key features of the learning environment that is designed to achieve the above mentioned objectives.

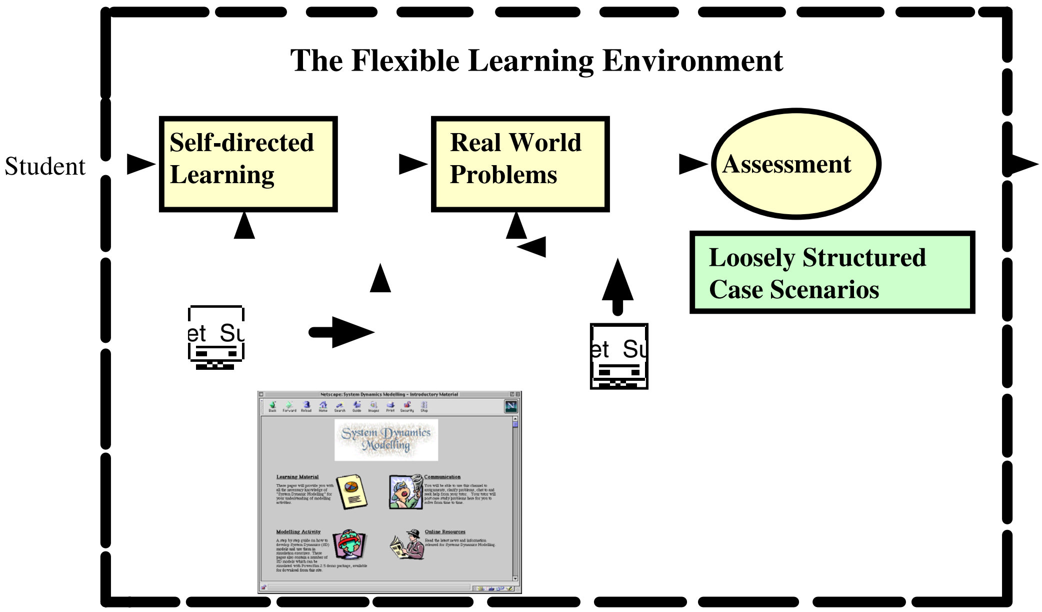
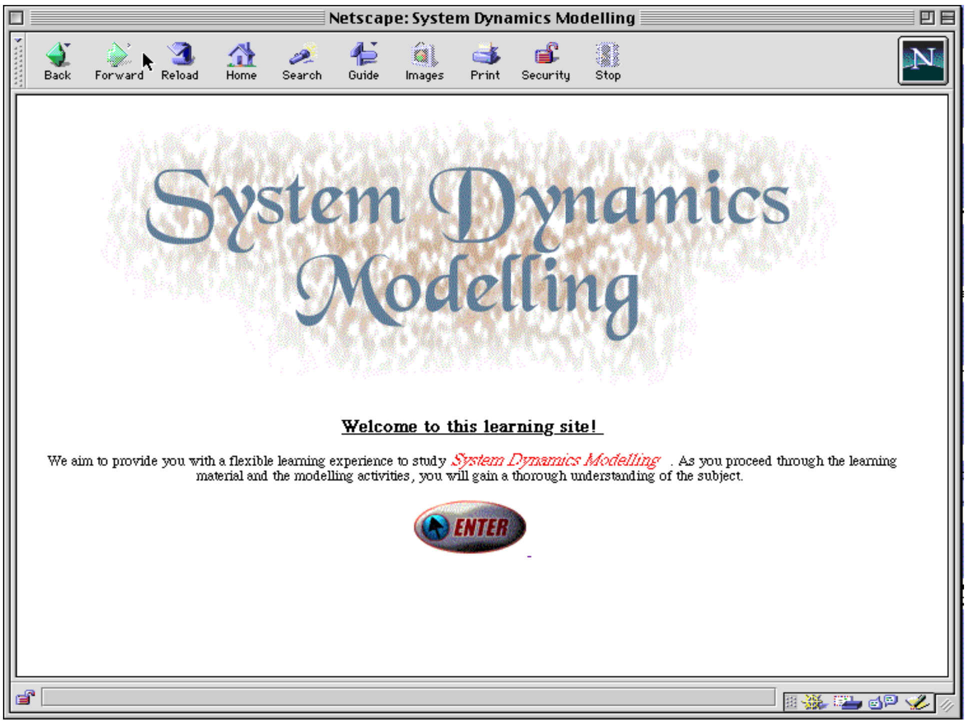


Figure 2. Key Features of the Flexible Learning Environment

An interactive Web site was developed as the hardware of this learning environment for students to use. The Web site provided a repository for instructional materials and an online meeting place. It also made available a means to access global information. These functions were included as components in the site and named 'Learning Material', 'Modelling Activity', 'Communication Access', and 'Online Resources'. Figure 3 shows the design of the first two pages of the site.

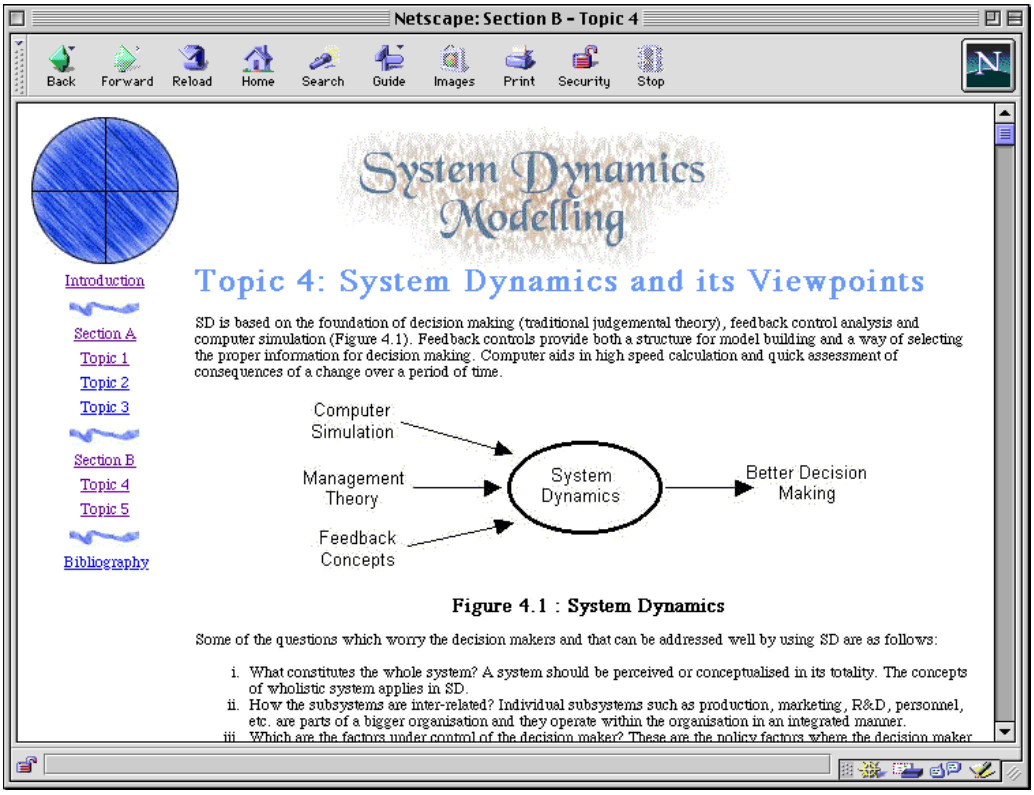


(i) The home page

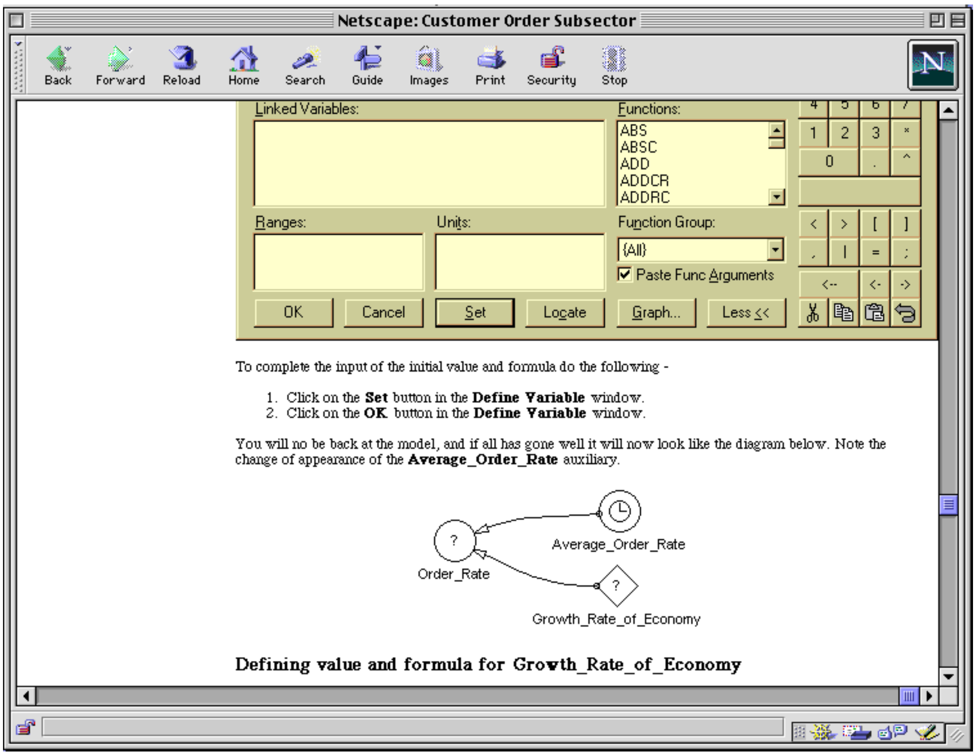
(ii) The navigation page

Figure 3. The First Two Pages of the Web Site

The 'Learning Material' component presented students with the basic subject matter of systems modelling. Students go through this component in a self-directed manner to gain an understanding of the knowledge on model building to prepare them to attempt the 'Modelling Activity' component. This activity component was a step-by-step guide on how to develop systems models, which can be used for simulation exercises. Models were simulated using the PowerSim demonstration package, which is a commercial computer application software that the project team has been given full licence to use. PowerSim is an intelligent application software that can enable students to develop a model and change the problem parameters of the model for simulation. The implication of change is presented graphically on screen. This software was installed onto the central server as part of the 'Modelling Activity' component for students to download. All learning material was structured in a hypermedia format allowing students to access, in any sequence, the information they needed at any moment of their study. The 'Learning Material' and 'Modelling Activity' components are put in place to assist students to acquire a fundamental understanding in system dynamics. The knowledge of using the modelling application software, which is a basic competency that students need to master before they could solve real world problem cases, are presented in modelling activity component. Students' basic knowledge relevant to the subject where the problems are in question will be influential in shaping the information sought in the process of problem-solving. An existing knowledge base in the area concerned is one of the four types of process knowledge identified by Eraut (1992) that is essential to effectively acquiring information in problem-based learning. Snap shots of these two components are shown in the following Figure 4.



(i) A 'Learning Material' page



(ii) A 'Modelling Activity' page

Figure 4. Snap Shots of Basic Knowledge and Skill Components

The 'Communication Access' component of the Web site was equipped with the multiplatform groupware, FirstClass, which can enable collaborative interaction in the following forms: teacher to student(s), student(s) to teacher, and student(s) to student(s). Using this communication channel the teacher was able to distribute current information on real world case problems, hold discussions with different groups of students, monitor study, and to render assistance to study when required. Students can form discussion forums to discuss strategies in learning and solving the assigned problems as well as to submit simulated case solutions as file attachments to the teacher.

The ' Online Resources' component was designed to provide responsive resources to enhance students' learning, particularly the information needed to solve real world problems. These resources were student-focused and responsive in the sense that they were available for student access any time round the clock. A click on the menu 'Online Resource' will lead to pages on Annotated Hot Links, Usenet Newsgroups, References (with items that were linked to collections at Deakin University Library), and Electronic Library.

5. THE LEARNING PROCESS

Figure 2 depicts how the learning process can take place. Students study the material presented to them in the 'Learning Material' and 'Modelling Activity' components of the Web site at their own pace to acquire foundation knowledge and skills. They are expected to complete the 'Learning Material' component before attempting the 'Modelling Activity' component. A number of problem situations were included so that students can develop model building skills in this component. Having acquired basic knowledge in the field and skills in building and simulating models, students will then be required to solve real world problems by refining the loosely structured case scenarios presented to them, and then asked to formulate strategies to solve these problems. Through out the learning cycle, students have high degree of control in directing their own learning. The flexible nature of this learning environment allows on-campus students to access the Web site and network facilities in the School's computer laboratory at any time convenient to them. Off-campus students will be able to study this subject anytime at home or at the workplace in front of their desktop computer.

5.1 Problem-Solving Process

The way how this flexible learning environment facilitates the problem-solving process is illustrated with the help of Figure 5 below.

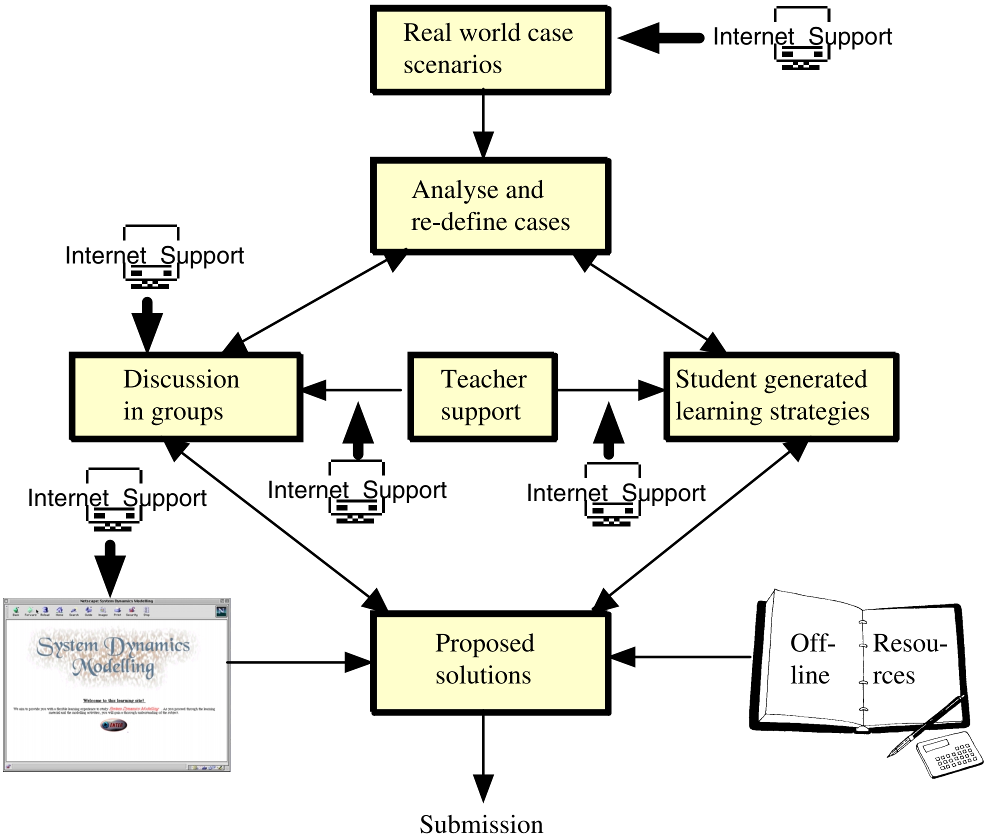


Figure 5. Problem Solving in Process

Four loosely structured real world case scenarios were presented online for students to work through. These were chosen problem situations from different sectors of economic activities which included business, industry, services, and environmental protection. Titles of these four problem cases were 'Environmental Impact Analysis', 'Schedule Overruns In Software Projects', 'Business Cycles', and 'Growth of Tourism'. Context of each of these scenarios and what problems students have to solve were provided together with guides for acquiring information. One example of such case description is shown in Box 1 below.

Environmental Impact Analysis

The material benefits offered by industrial growth have been partially negated by it's ill-effects. In fact we note that, in most cases, industrial growth has led to the pollution of the environment. Pollution levels often exceed the natural dissipation and absorption capacity of the environment, affecting the health of the community.

Environment degradation and falling health standards increase social pressure on the government. As a consequence, it may introduce a bill in Parliament making it obligatory for industries to implement pollution-control measures. Anticipating substantial cost on such implementation, industries lobby around, and often succeed in delaying the passage of the bill. The Government ends up agreeing to pay a subsidy or introduces a tax relief on investments made on pollution-control equipment. The maintenance of these equipment is often given the lowest priority. As a result, pollutants continue to get discharge into the environment while the records show that the industry has installed pollution control equipment. Additionally, the industry invariably passes on the costs incurred on maintenance of equipment to customers by increasing the production price.

Model this situation and test the present policy. What policy do you think can help tackle the pollution problem? Test these policies and comment on their suitability.

Box 1. Example of a Real World Case Scenario

While solving required problems, students work in small groups. Group activities typically would include:

- critically reasoning their way through the problems by bringing out prior knowledge they have learnt from the material presented in the Web site to identify additional information and knowledge they needed to better understand and manage the problems, and determined what resources they would use to gain the information and knowledge needed;
- consulting resources and working collaboratively to collect and interpret information including quantitative data as well as to link aspects of information together. Students supported each other in the form of peer tutoring to gain the knowledge and skills needed;
- criticising, refining, and sharpening the case context and formulating the best strategies in solving a particular case problem by synthesising what they have learnt;
- constructing and simulating model(s). Solutions are submitted electronically for assessment; and
- reflecting on the problem-solving learning experience – knowledge acquisition, self-directed interdependent learning, peer tutoring, etc.

Since the ready availability of up-to-date reference and information resources is vital to problem-based learning, students were encouraged to utilise the Web-based ‘Online Resource’ facility to access local and global sources of information. As mentioned earlier, this facility would provide responsive access to information at anytime reducing the time constraint that impeded students’ access to information services outside normal opening hours. Students also drew on off-line resources located in libraries, workplaces, government agencies, information bureaus, etc. Interaction among peer students was enabled by the functions allowed by the Web version groupware FirstClass. Off-campus students used synchronous and asynchronous communication to discuss and convey ideas as suitable at their own arrangement while on-campus students used a mix of face-to-face meeting and online conferencing at times they considered to be effective.

Through online interaction, the teacher was able to stimulate and guide student learning at the initial stage. However, as the groups became proficient, the teacher withdrew gradually allowing the groups to increase independence. The conferencing capability also facilitated the teacher to present feedback on problem solutions to students in the shortest time.

6. CHALLENGES AND POSSIBLE FUTURE DEVELOPMENT

Internet-based media can provide means of communication and global access to information that are vital to flexible learning especially when special learning strategies, such as problem-based approach and collaborative learning, that are adopted by this teaching project. But use of Internet-based delivery is not without its pitfalls. Limited by the current common bandwidth used in ppp/slip connection, it is impractical to deliver large size multimedia and application files. Feedback from a trial run of this project to selected numbers of on- and off-campus students showed that down loading of the PowerSim demonstration simulation software took more than twenty minutes from outside Deakin's LAN. As anything more than twenty seconds is beyond the patience level of most students, this has hampered the total effectiveness of the learning environment.

To solve this problem a hybrid delivery mode of using both the Internet and CDROM may be a future solution. The use of CDROM to deliver multimedia course material has two merits: (i) it allows a large repository for multimedia information, and (ii) it permits fast access to information. Therefore, an integration of CDROM and Internet technologies would provide a technical platform to effective flexible learning, particularly, of engineering courses where a large amount of information in multimedia format has to be delivered and special teaching strategies requiring student interaction have to be adopted for optimum effect.

7. CONCLUSION

An Internet supported flexible learning environment for system dynamics teaching is presented in the paper. The design and development of a teaching framework, which allows flexible access to study with respect to time, geographic location, learning pace, and learning style, is described in detail. The created learning environment pedagogically adopts problem-based learning approach to allow learners actively engaged in the learning process based on the learners' interest, curiosity and experience that would result in expanded insights, knowledge and skills. Moreover, the collaborative and self-directed learning experience that could be achieved by this teaching framework could improve student's skills in working in team situation, communication, and life-long learning. Furthermore, when expended to incorporate the use of CDROM together with Internet technology, this teaching approach would provide the framework to create efficient and flexible learning experiences for multi-modal course delivery. This learning environment can be generalised to make it suitable for use to other courses employing flexible delivery methods to ensure the demands of students with regard to course and modes of study are met.

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