DESIGN AND DEVELOPMENT OF VISUAL LEARNING TECHNIQUES TO CONSTRUCT CHEMICAL ENGINEERING SAFETY KNOWLEDGE

by

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Abstract

People working in the chemical industry require specific skills to deal with hazardous environments and to operate complicated machinery which often requires on site training. The importance of designing systems and environments with safe possible ways to train operators is essential for the chemical industries. Virtual reality offers the potential to train personnel in a safe highly visual and interactive manner.

Virtual Learning Environments(VLE) represent an entirely new form of educational technology. Virtual learning environments support similar forms of learning to 'real' ones but are not a physical space, like a classroom or lecture theatre, and learning may work closely together while not being active at the same time. Virtual learning environment can be used to enhance traditional instruction, which will as a result enhance a student's achievement. Virtual environment can be used to enhance traditional instruction, which will as a result enhance a student's achievements. Virtual environments lead to a greater depth of learning and engagement for many students. Virtual learning environments are keeping with the spirit of constructivism where teachers and students are active participants of knowledge formation not just the recipients of knowledge. The aim of the work presented in this thesis was to establish if constructivist education of chemical engineering safety practices was achievable using VLE.

A VLE was created based on an undergraduate laboratory experiment for the chemical engineering degree at The University of Nottingham. The VLE focused primarily on safety and hazard awareness issues of students performing the experiment. The VLE was created principally for the first year chemical engineering students and first time chemical engineering laboratory visitors. The effectiveness of this VLE was tested with positive results for the group for which it was designed.

Dedicated to my Mother, Induben Dholakiya and the loving memory of my Father Shantibhai Dholakiya

Acknowledgements

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Chapter One

Introduction

1.1 Introduction

Some aspects of learning, such as learning how to complete a process, are best tackled by having the learner build his or her knowledge through practice. We may refer to this process are 'constructing' knowledge (Manus, 1996). A good way to achieve this knowledge construction is by using a virtual learning environment in which learners are given the opportunity to learn by doing, without the associated dangers that would be present in a real environment. As an added advantage over other methods, a virtual environment can occur at any time and in any place. Depending on the setup of the course, learners may be in complete control of the topics and material learned. Because of the asynchronous nature of a virtual learning environment, students do not have to worry about other students or teachers' learning processes. Students in a virtual learning environment can use cooperative learning through discussions, chat rooms, and e-mail (Corey, 2004).

Most human activities carry specific risks. The risk profiles of industries change with time as certain hazards are overcome and new ones appear. The main hazards of the process industries arise from the escape of process materials, which may be inherently dangerous or may become dangerous at high pressures and high or low temperatures. A review of worldwide chemical or chemical-related incidents that have had a major impact on surrounding communities is summarised in Table 1.1 (King and Hirst, 1998).

As chemical industries become increasingly complicated and automated, the gap between operators and processes widens. Operators lose the ability to handle real processes as they manipulate plants via the use of control panels that include switches, alarms, recorders, monitors, and many other instruments. It is difficult for operators to know all of the necessary knowledge about relevant processes and emergency situations. Accidents in chemical processes arise mostly from operator error (Goh et al., 1998).

Widespread concern over the hazards of chemicals is an issue not only to those who work with them but also to the environment and the general public. Unless a chemical plant is well designed, it is difficult to prevent dangerous materials from escaping. Safety in chemical industries cannot be treated as a separate subject, as can design, production, or maintenance. Safety depends on both the technical skills and safety awareness of all employees (Schofield, 2000).

Incident	Impact
Flixborough in United Kingdom (1974) Vapour cloud explosion	28 fatalities on site; $232 million damage; damage to homes off site
Seveso in Italy (1976) Toxic material release	Widespread contamination on site and off site
Bhopal in India (1984) Toxic material release	300 fatalities, $20 million damage, mostly offsite
Mexico City, LPG (1984) LPG Explosion	2500 fatalities, many others injured off site
Chernobyl in Ukraine (1986) Fire and radiation release	31 fatalities; 300 square miles evacuated; widespread contamination
Sandoz warehouse, Switzerland (1986) Toxic material release	Major impact on ecology of Rhine River
Shell Norco refinery in the United States (1988) Vapour cloud explosion	7 fatalities on site; neighbouring town evacuated; damage exceeded $50 million; widespread damage to homes off site

Table 1.1: Selected major incidents (after Nasios, 2002)

Training has always been considered an important factor for staying competitive in a global economy. Employees need to remain up to date with the latest

methods and technology. Most would agree training is important. However, there is an obvious cost in developing or purchasing training materials and courses (Barton, 1997).

When all plant workers are required to attain routine safety training, it is a challenge for instructors to provide the training in an interesting, effective, timely, and cost-effective manner. Training should involve an introduction to basic hazards and plant procedures and also the use of personal protective equipment, fire alarm systems, and work safety processes. A trainee should be assigned to a particular plant to work alongside an experienced operator to receive practical instruction in all aspects of plant operation, including safety and emergency processes (Goh et al., 1998)

Traditional training methods present difficulties in helping employees gain in-depth knowledge of unusual or potentially dangerous occurrences from a safety viewpoint. It is also difficult for traditional training methods to simulate processes in the chemical engineering field, which would offer trainees the opportunity to practice and test their abilities and their knowledge. Traditional methods of training do not allow trainees to experiment with the different types of equipment involved in the chemical process unless the machinery is taken off line (Schofield et al., 2004).

Virtual Reality (VR) can be a powerful tool for training because people can grasp images much faster than they grasp lines of text or columns of numbers. Many industries have produced virtual reality training simulators, which are used for planes, submarines, power plants, tanks, helicopters, ships, trains, surgery, and air traffic control. Virtual environments provide significant benefits over other methods because they allow the trainees to make mistakes and to gain first-hand experience. Virtual reality systems have also the flexibility to structure different training scenarios, and they can monitor and measure the progress of every training session (Burton 1997). The main characteristics of a 3D virtual environment are as follows:

- The virtual environment is modelled using 3D vector geometry, meaning that objects are represented using x, y, and z coordinates describing their shape and position in 3D space.

- The user's view of the environment is rendered dynamically, according to his or her current position in 3D space; the user has the ability to move freely through the environment.

- At least some of the objects within the environment respond to user action; for example, doors might open when approached, and information may be displayed when an object is selected with a mouse.

- Some environments include 3D audio, which appears to be emitted from a source at a particular location within the environment. The volume of sound played from each speaker depends on the position and orientation of the user within the environment.

Computer-based learning has expanded into many different levels and forms. It is used in all levels of education—from elementary to graduate school. Some computer-based programs are offered in an actual classroom facilitated by a teacher. In more advanced forms of computer-based learning, many students may never meet their instructor in person. Learning provides a sense of discovery. Something new enters one's experience through learning, and the new knowledge alters what we know or what we can do to develop our skills. Learning is a process that cannot be continued within the boundaries of traditional learning; it can happen anywhere and at any time (Ranson et al., 1996).

A Virtual Learning Environment (VLE) represents an entirely new form of educational technology. A virtual learning environment is a set of teaching and learning tools designed to enhance a student's learning by including computers and the Internet in the learning process (Everett et al., 2002). A virtual learning environment may support forms of learning similar to a 'real' one, but it is not a physical space such as a classroom or lecture theatre. Learners may work closely together while not being active at the same time (Picciano, 2001). A virtual learning environment can be used to supplement traditional instruction, which will improve students' achievement (Lorenzetti, 2003). Students hesitant

to speak in class may be more productive in the discussions in a virtual learning environment in which the audience has been removed (Fryer, 2002). This leads to a greater depth of learning and engagement for many students.

Constructivism is a theory about how people learn. Based on the work of developmental psychologists, constructivism argues that people construct meaning through their interactions and experiences in their social environments. Constructivism presumes that prior knowledge and experience play a significant role in learning and form the basis for subsequent actions (Manus 1996). The virtual learning environment can promote constructivism by allowing learners to immerse themselves in the virtual experiment. Using virtual-learning models of real equipment allows risk-free, endless experimentation. Allowing users to learn within computer-generated environments provides the opportunity for them to make mistakes and suffer the costs without putting themselves or others at risk.

1.2   Aim of the research

The overall aim of this research is to establish whether a constructivist virtual learning environment would lead to a better understanding than would a conventional learning environment when teaching chemical plant safety and hazard awareness.

1.3   Objectives of the research

Individual objectives are to

- discuss the general suitability and potential of virtual reality technology for training application in the field of chemical engineering.
- develop a range of visual learning techniques to investigate the suitability of the virtual learning environment in the field of chemical engineering.
- investigate the application of the virtual learning environments as a teaching and learning aid for chemical laboratory safety and hazard awareness.
- evaluate the design and implementation of the virtual learning environment for promoting constructivism in the chemical engineering field.

1.4 Thesis overview

This thesis comprises two main parts. The first section, chapters two, three and our form a literature review of areas related to the research. The second section, chapters five six and seven, detail the design and development and conclusions

The major subject areas covered in this research are chemical engineering safety training, computer graphics and virtual reality, learning and constructivism. It was not possible to discuss all of them in a single literature review, so this review has been split into three different chapters. Thus chapter two discusses the available literature on types of safety training in the chemical industry. Computer Based Training (CBT) has been detailed in terms of its types with evolutions of the applications and the types of technologies used for CBT. The second part of that chapter reviews the available literature relating to learning covering the definitions and theories of learning. It also describes the theory of constructivism and virtual learning environments.

Literature relating to computer graphics and virtual reality covering the definitions and general application areas of computer graphics and virtual reality are discussed in chapter three. It also presents current uses of computer graphics and virtual reality for training aids and outlines some common virtual reality software. This chapter also reviews some examples of the evaluation studies that researchers and people in industry have conducted on their various uses of virtual environment technology. Chapter four reviews the literature related to learning technologies. It also describes the types of learning technologies with their application and evaluations.

Chapter five describes the design of the virtual learning environment of the bubble cap distillation column. This virtual environment was based on an undergraduate laboratory experiment for the chemical engineering degree course at the University of Nottingham. The second part of the chapter discusses the laboratory distillation procedure, set up shut down process including safety and hazards issues.

Chapter six details arguments on the hypothesis of this research work. It covers the evaluation of the designed column and of the results.

Chapter seven gives a brief overview of the findings of the thesis followed by a number of conclusions and recommendations based on the research, regarding the suitability and future applications of constructivism and virtual learning environments in chemical engineering education.

Chapter Two

Literature Review I

(Training and Learning Methods)

2.1 Introduction

This chapter discusses the available literature regarding the types of safety training in the chemical industry. Computer-based training (CBT) has been detailed with respect to the types and evolution of the applications and the types of technologies used. The second part of the chapter reviews the available literature related to learning, covering the definitions and theories of learning. It also describes the theory of constructivism and the virtual learning environment.

As covered in chapter one, there is widespread concern over the hazards of chemicals, not only to those who work with them but also to the environment and the general public. Unless a chemical plant is well designed, it is very difficult to prevent dangerous materials from escaping. Safety in chemical industries cannot be treated as a separate subject—such as design, production, or maintenance—but depends inextricably on both the technical competences and the safety awareness of all employees (King and Hirst, 1998).

The most detailed set of safety rules and procedures are meaningless unless they are implemented and kept under regular review. It is essential that the immediate causes of accidents are seen in the wider context of the organisation and management climate in which they occur, and it is important to focus on the design of systems and equipment in order to minimize the potential for human error (King & Hirst, 1998).

Harmful chemical compounds in the form of solids, liquids, and gases from the production process can cause toxic effects by inhalation, absorption, or injection. Airborne chemical hazards exist as concentrations of mists, vapours, gases, fumes, or solids. The degree of worker risk from any given substance depends on the nature and potency of the toxic effects and the magnitude and

duration of exposure. Information on the risk to personnel from chemical hazards can be obtained from a material safety data sheet, which is a summary of the important health, safety, and toxicological information on the chemical or mixture's ingredients (OSHA, 1998).

Evidence from everyday life shows that well-trained and careful workers can avoid injury on a dangerous job, whilst untrained and careless workers may be injured, even under the safest possible conditions. Before any employee can work safely, he or she must be shown safe procedures for completing tasks. The purpose of safety training should be to improve safety awareness in employees and to increase their performance on their jobs without putting themselves and their fellow employees in danger. Acknowledgement of the hazards, their effects, and the required techniques to avoid or improve those effects must be provided to all personnel in a process industry (Schofield et al., 2001).

Training helps trainees acquire the skills, knowledge, and attitudes needed to make them competent in all aspects of their work. The training may include formal off-the-job training, instructions to individuals and groups, and on-the-job coaching and counselling. Ensuring that people are competent may demand more than formal training. For example, a period of supervised experience in which to practice and develop new skills may be necessary as well (Kubias, 1982).

Training is comprised of both formal and informal teaching. Formal training describes that which is undertaken in a workshop or classroom and is essentially given off the job. Formal training may include induction courses for new starters as well as those designed to update and reinforce employees' knowledge of safety techniques and practices. Informal training is essentially practical in nature and normally takes place on the job (Burton, 1997).

In reality, a training programme will normally have more ambitious goals with regards to improving safety and efficiency. It has been observed, in connection with the effectiveness of different training methods that people generally tend to remember

- 10% of what they read.
- 20% of what they hear.
- 30% of what they see.
- 50% of what they read and see.
- 70% of what they say.
- 90% of what they say and do. (Kubias, 1982)

These statistics show that trainees retain the information best if they follow oral and visual instructions, understand the job themselves, and recall the important points of the job as they proceed. Therefore, the best training methods are those that provide trainees the opportunity to obtain training by saying and doing. According to Ridley (1994), there are benefits to active participation by the trainee. This participation can best be achieved by using training aids that suit the circumstances of the industry, the company, and the trainee.

2.2   Types of training media and methods

Below is a short description of the types of training media used to train employees. The two types of training methods are 1) traditional training methods, and 2) computing-based training methods. Traditional training methods have been used for a long time to train employees. Computer-based training is the type of training method that uses computers and technology.

For years, classroom training was regarded as the most cost-effective way to teach. The trainer follows a course outline to ensure that he or she is covering the required content. A classroom-based training program may use several different types of media to deliver its content (King et al., 1998).

2.2.1   Printed media

Books and notes are easily produced, and other methods that are used to deliver the training program—such as a booklet or manuals—are usually provided for reference. Books are classed as passive learning aids. Although the trainee may respond to the book, the book itself cannot detect any difficulties the trainee may be having (Goh et al., 1998). Written exercises may require answers. However, there is little to stop the student from cheating or losing interest

unless the book is used in conjunction with another delivery method. A prerequisite for using books and notes is the literacy of the student; the student must be able to comprehend and understand what is being written. A company's manual is a good example of training using printed media. The manuals cover company details, safety, health hazard awareness, and proper use of safety equipment. The manuals are written clearly in easy-to-understand language.

2.2.2 Personal instruction

Training given by personal instruction varies from individual coaching to lecturing in which trainees can often solve their difficulties at the same time. Spoken words are not a good training medium as they can be easily misheard, misunderstood, or forgotten. The personal instructor should have additional demonstrations such as projection slides, videos, or notes for reference (King & Hirst, 1998).

The effectiveness of such a traditional medium mainly depends upon the skills of the instructor and tends to vary with each class depending on the instructor's mood, attitude, and classroom setting, among other things. The advantage to this approach is the ease of contact students have with instructors and the opportunity they have to ask many questions freely. However, others may find the group setting intimidating and may fear asking any questions (Goh et al., 1998).

2.2.3   Films and videos

Films and videos are two of the most powerful tools of traditional media. They combine moving and real-life images with the spoken word. This helps trainees overcome potential confusion or misunderstanding of a situation. Films and videos require considerable skills, resources, and planning to produce. During video training, the trainees watch an expert perform a task. Trainees using video do not have the opportunity to practice or engage anyone in their learning, but they do watch a more knowledgeable person performing the tasks. Watching an expert demonstration does not result in acquiring a familiarity with the task at hand (Bosco et al., 2000). Given that the nature of the task is to gain declarative

knowledge and situation awareness, the act of watching is essentially a passive activity.

In general, traditional training media have been identified to have the following limitations:

- Very hard to transfer the training materials (paper and pencil, verbal games)

- Same set of training material being used from year to year

- Time consuming and more risky if training has been arranged at the chemical plant

- Classroom training limits number of trainees

- Limited knowledge of instructor limits knowledge of trainee

2.2.4 Computer-based training (CBT)

Computer-based training (CBT) is a type of training delivered via computer. Computers are a useful training medium, especially when instructors are in short supply. Bosco (2000) described the related terms and techniques for CBT as follows:

Computer-Assisted Instruction (CAI): Computer-assisted instruction (CAI) delivers instruction through the medium of a computer. This is an alternative term for computer-based training. The use of computers in a training programme requires that each person becomes familiar with the system used. This may place a burden on the resources if the time required to achieve this is significant. An instructor can use computers at different times and places according to the characteristics of the subject matter, the trainees, and the available software and hardware. Computer programs can be used for practice, revision, one-to-one instruction, problem solving, or simulations during the applications.

Computer-Assisted Learning (CAL): Computer-assisted learning (CAL) is the term that describes a computer being used as an additional tool to provide aid in a traditional learning situation, such as classroom training. The computer is a device to assist the instructor during the training process, which may include a

blackboard or handouts. CAL systems may contain a hidden model of a real-life situation to which the trainee must respond. By providing a number of these situations, the trainee can fully understand the environment. This type of instruction can be useful for specific situations that are complex and do not necessarily have one correct answer.

Computer-Assisted Testing (CAT): Computer-assisted testing (CAT) is a method of assessing an individual through the medium of a computer. Individuals take the test at the computer, and the computer records and scores the test. An example is the Driving Vehicle Licensing Agency (DVLA), which has introduced a computer-based test for hazard precaution. The test covers some test practice videos in which the learner has to click the mouse to identify developing hazards.

CD-ROMs are a good way to deliver training to employees in a variety of situations. CD-ROMs allow the training to come to the employee instead of the employee going to the training, allowing employees to access CBT at their own workstations when it is convenient for them. Applications on CD-ROM can also be installed on a dedicated hard drive to deliver training at a central location.

Another CBT delivery technology is the Internet or the World Wide Web (WWW). While the WWW can be a good way to deliver CBT to employees, an Intranet can even provide more flexibility and opportunities to deliver high quality CBT. It uses the same communication protocol as the Internet, and a browser is used to view information (Petroski, 1997).

These CBT delivery methods are being used to train employees on everything from company policies to sales skills. Employees are being trained with CBT to operate elaborate machinery, to use new software packages, to identify signs of drug abuse in the workplace, or to improve communications skills. These skills were taught before computer technology was available; however, the technologies have allowed companies to realise increased performance and decreased training time and costs. One more benefit that computer technologies

allow is the ability to deliver the training material based on prior experience, practice, and test performance (Petroski, 1997).

Employees taking CBT courses using multimedia actively participate in the training by the nature of the delivery method. Ongoing interactivity increases a student's interest in the training, which, in turn, can result in a higher retention of the training material. Training effectiveness can also be increased when CBT is used to simulate dangerous or costly training situations. In those cases, a generative (an instructional approach that encourages employees to build their own meanings of concepts based on individual experience) or discovery approach to training is often viewed as the best way for employees to learn important procedures and problem-solving skills (Bosco et al., 2000).

2.2.4.1 Techniques used for CBT

Most CBT uses one or more of the techniques discussed here. Included are tutorials, drill and practice, training games, simulation, and problem solving.

Tutorial: The most commonly used CBT technique is the tutorial. It is used to introduce new information that must be taught in a sequential manner. It is useful for teaching factual information, simple discrimination, rules, and the simple application of rules. K Alliance is a California-based company that provides CBT tutorial videos. Self-paced CBT tutorial videos allows users to work on their own PC or laptop when and where they want. The training video contains self-assessments and quizzes. (URL available at http://www.kalliance.com; last updated April 2008).

Drill and practice: Another commonly used technique is known as drill and practice. It provides opportunities for practice when mastery of a new skill or information is desired. It should be used after initial instruction. The PLATO system from Control Data is one of the first computer-based training programs that was developed late 1950s and early 1960s. This system used a drill-based approach to train and allowed students to skip lessons they already knew. PLATO evolved with technology, bringing in academic- and corporate-world

courseware for training students together in a group. (URL available at http://www.kalliance.com; accessed 4 April 2008.)

Training games: In training, games are commonly used to supplement traditional lecture-based or online delivery of information. Prensky (2004) explains, "In most cases, digital game-based learning is not designed to do an entire training or teaching job alone." The role of games is primarily to reinforce the understanding of presented material and to add variety in training.

The Thiagi Group has developed a range of more than 150 ready-to-use online training games and activities to engage participants. Some of them are Action Plan, Artful Closer, Best Summaries, and Building A Great Business. The idea behind such training games is to improve personal and professional skills of participants. Because the group of participants may vary, using different ideas and tricks, like match and mix, cognitive simulation, interactive lecture, matrix game, etc., can bring something for everyone. (at URL available at www.Thiagi.com/Freebies/TrainingGames; accessed 11 August 2007.)

Simulation: The technique of simulation is most often used when practicing a skill in a real situation would be too costly or dangerous. Simulation provides an opportunity for experimentation and allows students to test assumptions in a realistic situation. Simulations are also used to model real-world situations, which are not physically dangerous or costly, to build realism and relevance into the training situation.

In some sectors of society, simulations are a recognised part of training. Simulations are heavily used in business and economic sectors. In medicine, simulations are used to test various treatments and to train medical staff without the need to cut people open. Simulation in the military is extensively used for quick and safe fighting-scenario training. The simulation field has its own long-established research community, which is grounded in a range of disciplines including mathematics, logic, philosophy, and engineering (Kirriemuir, 2004).

Problem solving: Problem solving is one of the most challenging techniques used in CBT. It helps students to develop skills in logic, problem solving, and following directions and is generally used to augment higher-order thinking skills. Most of the courses use a simple case study and basic exercises such as multiple choice and true or false questions. Feedback is given after each exercise.

CBT incorporates one or more of these techniques. A training game, for example, might have some of the elements of drill and practice; a tutorial might use problem solving questions. If one or more of these techniques is right for meeting any training requirements, then CBT may be an appropriate training method (Manus, 1996).

The Institution of Chemical Engineers (ICHEME) in the United Kingdom and the American Institute of Chemical Engineers (AICHE) provide a variety of training packages, which include courses, slides, and video tapes on detailed technical information about safety and environmental aspects of chemical plants. For example, "human error" is a safety training package of ICHEME, which contains 70 slides, examines 15 accidents wrongly attributed to human error, and explains how the real causes are faults in management, control, design, systems of work, training, labelling, and notices (ICHEME, 2000).

CBT has several advantages over classroom lectures. Computers as a training medium provide consistency every time a course is taught. Once a training course is established, the tone, delivery, and style will not vary, thus guaranteeing the quality of the material being delivered. Furthermore, CBT allows students to proceed at their own pace without fear of being embarrassed if they choose to review one section three times or skip to other sections. Most students view this training as faster because it is self-paced, and they claim that they learn and retain more this way than from traditional classroom lecture. There is also a significant reduction in instructors and, hence, a large saving in staff time, as CBT only requires one subject-matter expert to be available on call or through electronic mail to answer questions (Manus, 1996).

Two other advantages of CBT over classroom training are in testing and course documentation. The computer makes the routine, monotonous task of testing relatively simple. Challenge tests can be offered before the course begins, which allows knowledgeable students to test themselves on the course requirements. Modular testing can be established before or after each unit, or a comprehensive exam can be offered at the end. The test questions can be randomly generated from an exam database, thus eliminating the concern that students could memorise the exam. Students can take an examination once—or as many times as the course administrator allows—and receive immediate feedback on the test results. Those students who are continuing to fail the exam can be blocked from further testing until a course administrator is contacted. The date, time, place, and student information can be automatically recorded and transferred to other training databases. Administration of a large volume of tests becomes easy with use of a computer (Filipczk, 1997).

2.2.4.2 Evolution of CBT

Secondary-school students were distributed into control and experimental groups. The assessment of the experimental group was done using computers, whereas that of the control group was done through a written test. The statistical evaluations displayed a higher achievement rate for the experimental group that received a computer-assisted test. Johassen (1991) compared the traditional learning strategies with computer-based activities. Applications and the assessment were checked after the students were distributed into control and experimental groups. The results of the evaluations showed that the experimental group was more successful at answering the questions of the chemistry achievement test than were the students in the control group.

In another study, Filipczak, (1997) compared CAI with traditional teaching methods on sixth-grade students in science classes. The students of the experimental group were taught with CAI in addition to traditional teaching methods. The students of the control group were taught through problem solving. The topics were static electricity, electrical transmission, electrical wires, and Ohm's laws. The science achievement rates of the two groups were

compared through a test, and the group that was taught through CAI was found to be more successful.

2.2.5 Virtual reality as a training medium

Virtual reality (VR) is a rapidly growing technology that utilises the increasing power of computers to simulate real or imaginary environments and situations with a high degree of realism and interaction. It is an emerging technology with potential applications in areas such as product design and modelling, process simulation, planning, testing and verification, real-time shop floor controls, training, and maintenance (Cox 2003). In fact, virtual reality has already been applied to a wide range of problems associated with manufacturing, industrial maintenance, post-production training, and customer services in areas such as visualisation of complex data, robot control, remote operation of equipment, communication, training and planning, and virtual prototyping and design. The success of those applications is based on a realistic virtual environment (Schofield, 2001). Further details on the use of VR as a training medium and on its various applications are discussed in the next chapter.

2.3 Definition and theories of learning

The term *learning* refers to those changes in our behaviour that result from contact with our environment and interactions with other people. Roger (1996) defined learning as 'any activity that produces a relatively permanent effect on later activity'. Learning as a cycle begins with experience, continues with reflection, and later leads to action, which itself becomes a concrete experience of reflection (Kolb, 1984).

Learning provides a sense of discovery. When something new enters our experience through learning, we alter what we know or what we can do to develop our skills. When we learn to ride a bicycle for the first time, the skills we develop expand our capacity to engage in the world around us. Learning is a process that cannot be continued within boundaries; it can happen anywhere and at any time (Ranson et al., 1996).

Prensky (2001) did try to get a single answer of the question 'How do people learn?' which is similar to asking the question 'What is the true religion?' Most religious people are convinced that their religion is the true religion, and yet, according to the religions of the World Organisation, there are thousands of different religions in the world. In the same way, the answer as the question 'How do people learn?' will elicit many replies. Some of the examples of a variety of theories of learning, says Prensky (2001), are as follows: learning happens when one is engaged in hard and challenging activities; learning comes from observing people we respect; learning comes from doing, through coaching, through failure, from models, from mistakes, from stories, by playing, aurally, visually, kinetically, through feedback, through reflection, and so on. Following are some of the learning methods.

2.3.1 Teacher-based learning

Traditionally, the teacher transmits information that the learner receives. Teaching practices focus on lecture as a means of conveying information and on the traditional paper/pencil, multiple choice forms of assessment. In traditional approaches to teaching and learning, textbooks and lectures provide the truth that there is little room for questioning, independent thought, or learner interaction (Murphy, 1997). Cognitive theorists believe that the role of the teacher is to provide learners with opportunities and incentives to learn, keeping in mind the following concepts (Feden, 1994):

- All learning, except for simple rote memorisation, requires the learner to actively construct meaning.
- Students' prior understanding and thoughts about a topic or concept before instruction exert a tremendous influence on what they learn during instruction.
- The teacher's primary goal is to generate a change in the cognitive structure of the students' way of viewing and organising the world.
- Learning in cooperation with others is an important source of motivation, support, modelling, and coaching.

2.3.2 Active learning

'Active learning' is an essential part of student-centred, work-based, and experiential learning. Schofield (2005) defines the term active learning as learning that affects a student's attitude or teaching methods that may force a student to be active. As a term to distinguish training that requires student activity, active learning is learning in which a learner speaks, writes, performs experiments, plans, e-mails, or even makes choices between Web links. When a learner is actively involved with the learning process, Cotton (1995) has found the following advantages:

- Attention: active learning helps solve the problem of maintaining attention. When taking an active part in the process of learning, the student will not have 'micro-sleeps' when attention wanes.

- Long term memory: the learner takes a personal stake in learning and a sense of personal ownership of the new knowledge.

- Motivation: active students are usually willing partners in the learning process, and so the teacher does not have to drag reluctant students through education or training processes.

- Individual attention: active learning will only work if the teacher organises a session so that each person can take part in the learning process and individual needs can be taken into account.

2.3.3 Experiential learning

Kolb proposed a four-stage learning process with a model that is often referred to when describing experimental learning (McGill et al., 1995). The process can begin at any of the stages, and it continues, that is, there is no limit to the number of cycles that comprise a learning situation. This theory asserts that, without reflection, one would simply continue to repeat mistakes.

Kolb's research found that people learn in four ways are likely to develop one mode of learning more than another. As shown in the 'experimental learning cycle' model in Figure 2.1, learning is described as

- Through concrete experience.
- Through observation and reflection.

- Through abstract conceptualisation.
- Through active experimentation. (McGill et al., 1995)
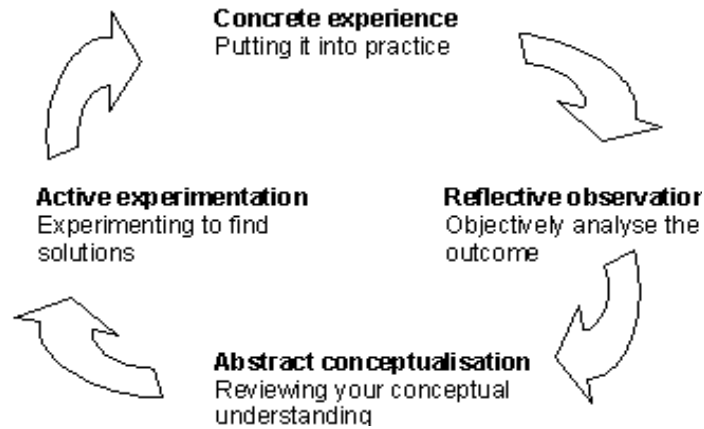
Figure 2.1: Kolb's Experimental Learning Cycle (after McGill et al., 1995)

People learn from their experience, and the results of learning can be assessed and perhaps certified for college credit. At the same time, programs of sponsored experiential learning are on the increase in higher education. Internships, field placements, work/study assignments, structured exercises, and role plays, gaming simulations, and other forms of experience-based education are playing a larger role in the curricula of undergraduate and professional programs. For many so-called non-traditional students—minorities, the poor, and mature adults—experiential learning has become the method of choice for learning and personal development. Experience-based education has become widely accepted as a method of instruction in colleges and universities across developed countries (Kolb, 1984).

2.3.4 Constructivism

A basic concept of constructivism is that for learning to occur, one needs to recognise and build on prior learning. In other words, learning should be constantly revised and built on past experiences. The term constructivism refers to the idea that learners construct knowledge for themselves. Each learner individually (and socially) constructs meaning as he or she learns. Bruner (1966) stated that the learner selects information, constructs knowledge, and makes decisions with the aim of integrating new experiences

into his/her existing knowledge. Constructivism provides meaning and organisation to experiences and allows learners to go beyond the boundaries of the information given. Moreover, a curriculum should be organised in a spiral manner so that learners can build upon what they have already learned. The principles Bruner believes are listed here:

- Instruction must be adequate and contain the experiences that make the learners willing and able to learn (readiness).
- Instruction must be structured in such a way that it can be easily understood by the learner.
- Instruction should be designed to facilitate extrapolation (going beyond the information given).

According to Papert (1993), constructivism involves construction in which learning is an active process during which people actively construct knowledge from their experience in the world. The role of learners in a constructivist environment is active and not passive. They are encouraged to be independent thinkers and problem solvers. In traditional education, the role of the instructor is seen as that of a transmitter of knowledge. In the constructivist classroom, a teacher's role changes significantly. The role of the teacher in the constructivist classroom is to act as a "guide on the side" (Brooks, 1993, 1995). Their job is to provide opportunities for learners to expand their knowledge in an active and engaged format. The teacher cannot assume that all learners have the same background knowledge or experiences on which to build new knowledge. Instruction has to be designed to make the missing connections for learners.

If learning is constructed, the attitudes, beliefs, and knowledge a learner brings into a new situation matter. The existing learning becomes the foundation for whatever learning follows. If this ''foundation'' is weak, building on it may be difficult or unreliable. As a result, it would be ideal if a learner's knowledge, attitudes, and beliefs were evaluated when entering a learning situation (Brooks et al., 1993). Two types of constructivism can be described: 1) cognitive constructivism and 2) social constructivism.

2.3.4.1 Cognitive constructivism

According to Fosnot (1996), Piaget's theory of cognitive development suggests that humans cannot be "given" information that they automatically understand and use; they must "construct" their own knowledge. They have to build their knowledge through experience. Experiences allow them to create mental images in their minds.

2.3.4.2 Social constructivism

There is a great deal of overlap between cognitive constructivism and Vygotsky's social constructivist theory. However, Vygotsky's constructivist theory, which is often called social constructivism, has much more room for an active, involved teacher. For Vygotsky, the culture gives the learner the cognitive tools needed for development. Adults, such as parents and teachers, are there to provide the tools of the culture, including language. The tools provide a learner cultural history, social context, and language. Today they also include electronic forms of information access (Fosnot 1996).

2.3.5 Virtual learning environment and constructivism

Virtual 5eality (VR) and the virtual learning environment (VLE) have become increasingly confusing terms. For example, Moore (1995) states that "virtual reality falls into three major categories: text-based, desktop-based, and sensory-immersive VR." These categories incorporate a wide range of technologies, each with quite distinct pedagogical issues. Similarly, the term virtual learning environment (VLE) is now used to include any Internet or Web-based learning resources with associated discussion tools. The areas of application and evaluation of VLEs are discussed in chapter four. Consequently, the 3D learning environment focuses on a particular type of virtual environment that makes use of a 3D model (Moore 1995).

Moshman (1982) identifies three distinct interpretations of constructivism, which these approaches all draw from to varying degrees. He labels these *endogenous*, *exogenous,* and *dialectical* as summarises them as follows:

Endogenous constructivism emphasises the individual nature of each learner's knowledge construction process and suggests that the role of the teacher should be to act as a facilitator in providing experiences that are likely to result in challenges to learners' existing models.

Exogenous constructivism is the view of formal instruction, in combination with exercises requiring learners to be cognitively active, which can help them form and refine their knowledge.

Dialectical constructivism is the view that learning occurs through realistic experience. However, learners require scaffolding provided by teachers or experts.

A constructivist analysis of virtual learning environments
This section discusses the theoretical potential of virtual learning environments from a constructivist standpoint based on Moshman's three interpretations of constructivism. The discussion focuses particularly on the aspects of virtual learning environments that make them different from other types of interactive multimedia or online learning environments.

Virtual learning environments and endogenous constructivism
The endogenous interpretation of constructivism emphasises the discovery of knowledge through the learner's engaging in an active exploration process. There are two ways in which virtual learning environments can be designed, both of which are consistent with this interpretation. The first includes simulations of the observable world and simulations of abstract concepts. The second is an interface to a complex information space, which can be an alternative to a standard Web or hypermedia interface. These are each explained with reference to examples in the following paragraphs.

The use of virtual simulations is consistent with the endogenous interpretation of constructivism, which highlights for the learner the discovery of knowledge through their interaction with the environment rather than from direct instruction. The simulations can provide a realistic framework in which

learners can explore and experiment, with these explorations allowing the learner to construct his or her own mental model of the environment. The interactivity inherent allows learners to see immediate results as they create models or try out their theories about the concepts modelled (Rieber, 1992).

There are a number of circumstances in which the use of a virtual learning environment may be preferable to the exploration of a real environment. One such circumstance is the exploration of places that cannot be visited, such as historical places, outer space, or the ocean floor. For example, Alberti, Marini, and Trapani (1998) describe a virtual environment modelled on a historical theatre in Italy. Another is the exploration of microscopic environments, such as molecular structures. These types of virtual environments can provide a greater sense of realism than other types of simulations based on 2D animations or photographic material, because the learner can move freely through the environment and view it from any position (Moore 1995).

Virtual learning environments and exogenous constructivism
The exogenous interpretation of constructivism emphasises the role of direct instruction to help the learner to form his or her own mental model of the ideas to be learned, supported by activities that allow the learner to test and further modify his or her knowledge representation. These activities could be carried out using a virtual environment, which simulates part of the knowledge area.

An alternative to surrounding the virtual environment within a set of instructional resources is to model a framework in which the learners apply their knowledge. It can be argued that there will be better transfer of learning. Especially, virtual environments can provide a level of visual realism and interactivity consistent with the real world. The ideas learned within the environment should be more readily recalled and applied within the corresponding real-world environment. This is a logical effect of the ideas that knowledge can be internally connected to experience (Baddeley, 1993).

Virtual learning environments and dialectical constructivism

The dialectical interpretation of constructivism highlights the task of reliable activities by the learner with support provided by experts or teachers. Groups of learners working together and developing their understanding of concepts through a social learning process is also important. The use of computer-supported collaborative learning (CSCL) environments, which allow learners to communicate and ideally work together on tasks, is useful. It is important for distance education students who otherwise may not have the opportunity to work with other students. Multi-user virtual environments with embedded communication tools have potential as CSCL tools.

2.3.6   Motivation

Motivation is one of the factors affecting learning. Motivation can be defined as the reason for an action, and it gives purpose and direction to behaviour. Motivation comes from two sources:

• Extrinsic (external causes)

• Intrinsic (internal causes)

Extrinsic motivation has external causes, which can include circumstances, situations, rewards, or punishment. Intrinsic motivation comes from internal causes, which include involvement in a behavioural model, thought processes, actions, activities, or reactions for their own sake and without an obvious external incentive for doing so. A hobby is an example of intrinsic motivation (Clark, 2004).

Self-confidence

All possible effort needs to be made to encourage self-belief and self-confidence in learning. Those with low self-esteem and low self-confidence are more likely to avoid being positive and to give up in the face of difficulty (Manus, 1996).

The amount of time and effort that a learner can put into achieving goals is also important in learning. Self-doubts can be easily cleared when learners hit obstacles, experience frustration, and judge themselves as incompetent.

Games deal with this issue by building confidence through scaled designs. Entry levels are usually easy, and skills levels are raised gradually as the learner gains confidence and incremental success. Self-reference is also a powerful motivational factor (Clark, 2004).

Challenge

Challenge is a powerful motivator that increases attention and helps processing in learning. Challenge works because success in overcoming challenges increases one's sense of achievement and self-esteem or self-belief. Games are basically challenging. They succeed in managing challenges in such a way that playing becomes compulsive. It is often through measured success and reward patterns that one keeps playing. The normal pattern is to ease the player in with just enough challenge to produce early success and then to up the chances gradually so that achievement is felt as a genuine result of better skills (Clark, 2004).

2.4 Summary

The associated hazardous and dangerous nature of the chemical industry and the accidents that have occurred in the past are directing the importance of safety in chemical process education and training methods. Trainees should be provided a safe environment in which they can build an understanding of safety and hazard awareness.

Traditional training methods have a number of limitations over computer-based training methods. When it comes to training chemical plant operators, computers can be the most effective medium of providing safety training without any associated risk. Trainees can obtain knowledge at their own convenience. Computer-based training can offer a great cost savings to an employer by saving the costs of time and staff training.

Games offer both, with the added advantage of performance achievement being a form of assessment in itself, that is, completion in and of itself is proof of competence.

Chapter Three

Literature Review II

(Computer Graphics and Virtual Reality)

3.1 Introduction

This chapter reviews the available literature relating to computer graphics and virtual reality theories and applications. It also presents current uses of computer graphics and virtual reality for training aids, outlines some common virtual reality software, and reviews some examples of the evaluation studies that researchers and the industry have conducted on their various uses of virtual environment technology.

3.2 Computer graphics (CG)

The term computer graphics is commonly understood to mean the creation, storage, and manipulation of models and images. Such models come from a diverse and expanding set of fields, including physical, mathematical, artistic, biological, and even conceptual (abstract) structures. Engineers and scientists have always capitalised on the value of pictures by expressing the results of their design work and calculations in the form of engineering drawings, charts, and graphs (Demel, 1984). Pictures and graphs are examples of 2D graphics, while 3D graphics include depth, which allows models to be built that can be rotated, shaded, and manipulated to produce complex animation.

3.2.1 Computer graphics theory

The term computer graphics refers to a set of computer applications that can be used to produce images and animations, which would not have been possible with the technology available only a few years ago. Computer graphics uses numerical models of real world objects to produce artificially created views. Each object is reduced to a representation consisting of points,

edges, and flat sides (Hollands et al., 1999). Computer graphics theory as a means by which to design an object is discussed here.

3.2.1.1 Coordinating systems

Within the field of 3D CG, there are three perpendicular axes, which are conventionally labelled as the x, y, and z axes (figure 3.1). The main point of reference in the 3D modelling space (or world) is called the world origin and is the point in space where the three axes intersect. Distances from the origin to a point in space are referred to as x, y, and z values. It is also possible to rotate about the three axes; these rotations are often referred to as pitch (rotation about the x axis), Yaw (rotation about the y axis), and roll (rotation about the z axis). This type of coordinate system is known as the Cartesian coordinate system, which was formalised by Rene Descartes in the eighteenth century (Watson, 2002).
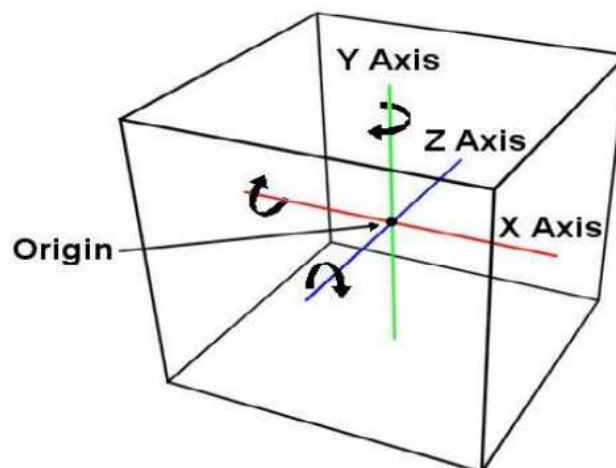
Figure 3.1: Computer graphics coordinate systems (after Watson, 2002)

3.2.1.2 Points, lines, and faces

Points, lines, and faces are among the basic elements that can be used to build 3D objects. A point can easily be defined by its XYZ values (values along x, y, and z axes, respectively). A line is defined by the XYZ values of its two end points. Similarly, a face is defined by the XYZ values of the points that outline it (the points on a face must all be planar). Figure 3.2 shows an example face in 3D space.
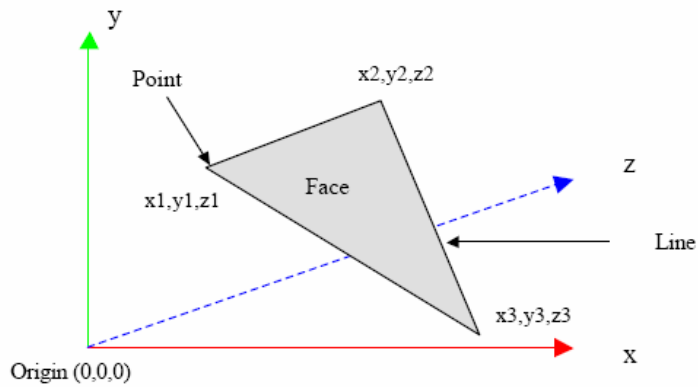
Figure 3.2: Example of a three-dimensional triangulated face (after Schofield, 2000)

A number of faces can be combined to produce shapes or models. Some complex models, such as a human skeleton, may require thousands of faces, while a simple box can be produced with just six faces (Schofield, 2000).

3.2.1.2 Faces and polygon mesh models

A model is made up of a number of faces, which form a representation of the shape of the object. A face can be regarded as a list of points that are all planar and which define its outline, where each point is defined relative to a local origin. Figure 3.3 is an example of a triangulated face (after Schofield, 2000).
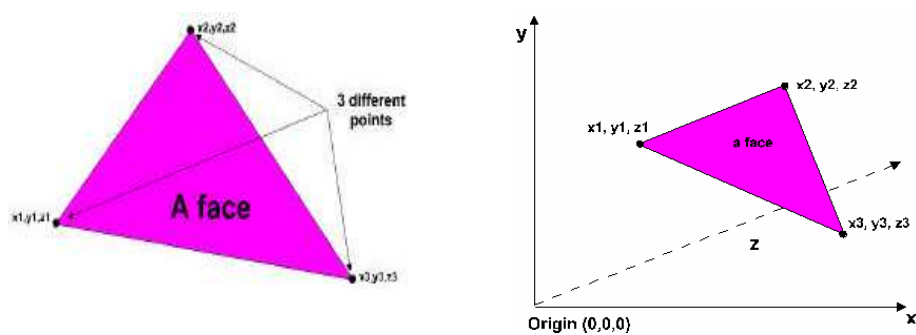
Figure 3.3: Example of a triangulated face (after Schofield, 2000)

Faces are made of materials that give the underlying colour of the face. The individual points that make up a face have a position relative to the origin (0,0,0) as shown in the right-hand part of figure 3.3. Faces are the primary

building blocks for shapes and models. Multiple faces can be used to build up more complex shapes and models to define positions in a virtual world. The faces, and hence complete models or elements of models, are defined around a local origin.

A popular representation of three-dimensional objects is the wireframe model in which the object is displayed as a set of straight lines that join the vertices together. Compared with shading an object, drawing a wireframe model is very fast. This will use a few hundred calls to the basic line-drawing utility, and the complete model will be drawn in a fraction of the time taken for a shaded representation. An example is shown in figure 3.4.
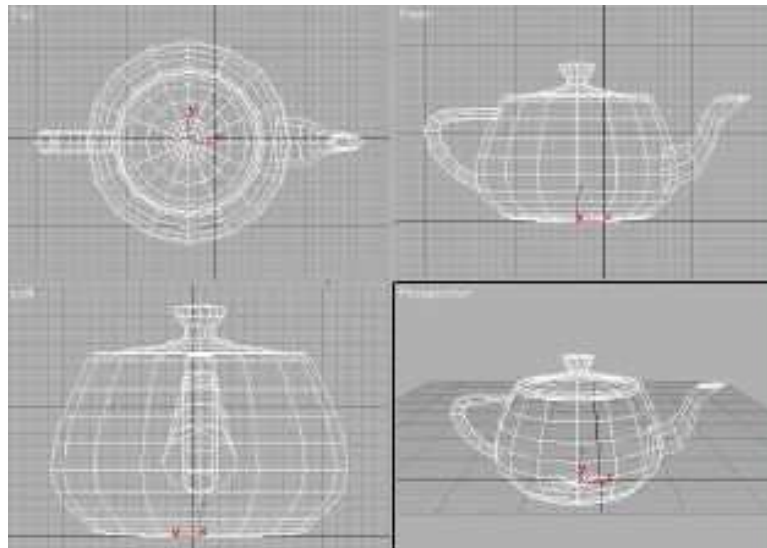
Figure 3.4: Example of a wireframe model (after Schofield, 2002)

Wireframes are often used as a preview facility when the final image is to consist of a scene made up of shaded objects, and wireframes are used extensively in CAD applications, both as a preview and as a final representation. Three-dimensional computer animation also makes extensive use of wireframe previews because the choreography of objects and the virtual camera can be worked out and evaluated using wireframe sequences. Current computers cope easily with wireframes of complex scenes in real time, and the images impart sufficient information for the animator to evaluate the sequence. In fact, wireframes are a pure analogy of the pencil or line tests

employed by traditional animators. Here, sequences are drawn with no colour to test the dynamics of the movement (Schofield, 2000).

A wireframe model is the simplest visualisation of an object represented as a polygon mesh model. Although a polygon mesh model is a simple concept, its exact form and the data structure in which it is embedded depend on the use to which it will be put. To produce a wireframe model, a simple data structure suffices for the polygon mesh and the individual faces of that mesh (Schofield, 2000).

3.2.1.4 Geometric transformations

Geometric transformations are the functions often used for modifying the shape of objects, their size and proportion, as well as their position in space. The most common transformations include translation, rotation, and scaling. Transformations can be applied to entire environments, single objects, or single primitives (points, lines, and faces). When applying a transformation, it is important to specify the axis or axes on which the transformation is to be applied and which origin—world or local—is to be used (Kerlow, 2000).

3.2.1.5 Lights, cameras, and shading

Lights are used to provide illumination to objects in 3D environments and can be very important to the final appearance of a virtual scene. There are many types of light sources, and each gives different atmospheric effects. These include ambient, infinite, point, spot, area, and linear. Figure 3.5 shows the difference between some of the commonly used light sources.

Infinitive light source   Point light source   Spot light source
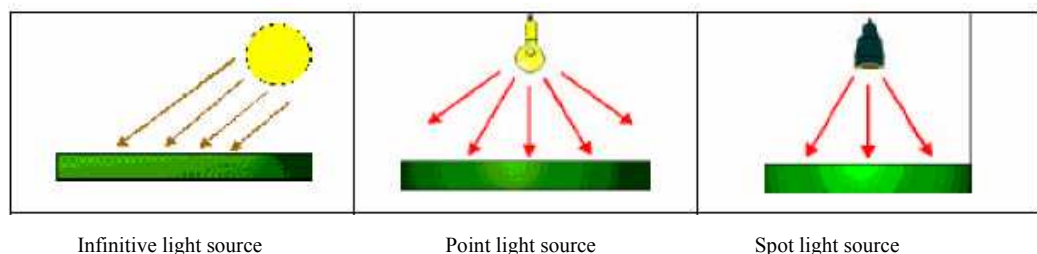
Figure 3.5: Example of light sources (after Nasios, 2001)

Ambient light is general background lighting, which is distributed evenly throughout an entire scene and often determines a general level of

illumination, or shade, of a scene. Since it is difficult or replicate light that is reflected off surfaces within a real environment due to the numerous time-consuming inter reflections, ambient lights are used to represent this reflected light (Nasios, 2001).

Infinite lights (also known as directional lights) use parallel light rays and have a direction, which defines the direction in which the light radiates. The sun is an example of an infinite light source, and some 3D modelling packages allow the user to place sunlight accurately by specifying the geometrical location of the scene and the date and time. A spot light is similar to a point light except the light is cast in a cone shape and is therefore directional. In virtual worlds, spot lights behave similarly to spot lights used in theatres; for example, they have hotspots. A spot light's hotspot is defined as the brightest spot of the light cast in the centre. Light sources can have any colour specified by using an additive colour model, usually the RGB model. The intensity and brightness of lights can also be modified to suit the environment (Schofield, 2000).

Shadows play an important part in making a 3D CG world realistic. They not only emphasise the direction of light, but anchor objects to the ground so they do not appear to be floating in space. Shadows, in a virtual environment, may have a number of parameters that can be set to change their appearance, including the colour of the shadow, the softness of the shadow edge, and the rendering method employed, which results in different levels of accuracy. Cameras are a small but essential detail in the rendering process, mostly because they define what we see in the shot, where it comes from, and how we see it. And while many of the steps in composing the shot have to do with arranging and defining the objects in front of the camera, defining and positioning the camera itself marks the beginning of the rendering process (Kerlow, 2000).

3.2.1.6 Texture mapping
The images assigned to materials are called maps, and they can offer a high level of realism. There are several different types of maps that are used,

including standard bitmaps such as .bmp or .jpg files, procedural maps such as repeating checker or marble designs, and image-processing systems such as compositors and masking systems. Maps can be assigned to most of the components that make up a material. By assigning the maps to different attributes of the materials, computer graphics artists can affect the colour, the opacity, the smoothness of the surface, and much more.

3.2.2 Computer graphics software

The most important part of three-dimensional computer graphics might be defined as the principles of modelling and rendering. Modelling is the creation of the geometry of the object to be rendered. The geometric primitives might be polygons or surface patches. The primitives might be created by defining the three-dimensional coordinates of the vertices of the polygons or might be created via interaction with a computer program, such as a CAD program or a simple program, which allows a user to create surfaces of revolution. Rendering, on the other hand, is the process of displaying the image of the object on the screen of a video display monitor, that is, determining which pixels will be displayed and what the shade (colour) of each pixel will be. Rendering might be accomplished via hidden-surface techniques, ray-tracing techniques, radiosity techniques, or some combination of these methods (Pierre, 1997).

Computer-aided design (CAD) is a commonly used software for 2D graphics, while in the field of 3D modelling and animation, there are many software packages that allow computer graphics artists to produce complex structures and realistic animations for commercial applications. AutoCAD is currently the most common CAD package worldwide. AutoCAD is designed for use on single-user desktop personal computers and graphic workstations. *3D Studio Max* from Discreet is a professional 3D modelling, animation, and rendering software package that delivers a unified, object-oriented platform for the creation of visual effects, character animation, and three-dimensional environments (Dassault Systems, 2000).

3.2.3 Computer graphics applications

Computer graphics are used routinely in such diverse areas as science, engineering, medicine, business, industry, government, art, entertainment, adverting, education, training, and accident reconstruction. The following sections discuss some of the application areas of computer graphics and present examples of such applications.

3.2.3.1 Design engineering

A major use of computer graphics is in design processes, particularly for engineering and architectural systems. CAD methods are normally used in the design of buildings, automobiles, aircrafts, computers, and many other products. Objects in a design application are first displayed in a wireframe outline form, which shows the overall shape and internal features of objects and allows designers to quickly see the effects of interactive adjustments to design shapes. Software packages for CAD applications typically provide the designers with a multi-window environment. Most of them have the ability not only to model but to be able to create design iterations quickly and collaboratively in an iterative process (Wheeldon, 1994).

Figure 3.6: A view of the psychiatric hospital of a residential tower block (after Nasios, 2001)

One project was the development of the new Birmingham University Hospital and the reallocation of the psychiatric hospital. Within a few weeks, a 2-km

squared area of the proposed site and surrounding area was modelled to produce rendered views of the new hospital and the relocated psychiatric hospital from various key locations. The percentage change in view was also calculated for the psychiatric hospital project section from these key locations. Figure 3.6 shows an image of the hospital, which was produced using computer graphics (Nasios, 2001).

3.2.3.2 Education and training

Computer-generated models of physical, financial, and economic systems are often used as educational aids, and they can help trainees understand the operation of the real system. Simulators and other specialised systems that provide graphics screens for visual operation are often used for practice sessions or training of ship captains, aircraft pilots, heavy equipment operators, and air-traffic control personnel (Cox, 2003).

Figure 3.7: A picture from an automobile simulator used to test driver reaction (after Evans & Sutherland, Inc., 2001).

Figure 3.7 shows a screenshot from a driving simulator, which is used to investigate the behaviour of drivers in critical situations. The drivers' reactions are then used as a basis to optimise vehicle design to maximize traffic safety.

3.2.3.4 Accident reconstruction

The ability to represent a range of accident scenarios on a computer screen and view those scenarios from any angle enables accident investigators and lay people to understand the underlying causes of an accident. Figure 3.8 shows a view of a reconstructed accident, which happened in Nottinghamshire. The three-dimensional computer model was built based on police digital survey data and photographs of the scene. The motion of both cars involved in the accident, based on police calculations, is clearly shown. Also, various witness vehicles are included in the animations based on locations and timing from witness statements (Schofield et al., 2000).

Figure 3.8: A view of the 3D computer model built based on digital survey data and photographs (after Schofield et al., 2000)

3.3 Virtual Reality (VR)

Virtual reality (VR) is a computer-created experience that allows a participant to believe and hardly differentiate a "virtual" experience from a real one. Computer graphics sounds and images are the main tools to produce virtual experiences of real-life situations. VR is also known as 'artificial reality', 'artificial worlds', 'virtual worlds', and 'virtualities'.

VR is the fully immersive, absorbing, interactive experience of an alternate reality through the use of a computer structure in which a person observes an artificial (i.e., simulated) environment by means of special human computer interface equipment and interacts with simulated objects in that environment

as if they were real. Several persons can see one another and interact in a shared artificial environment. This artificial environment is known as virtual environment (VE) (Kalawsky, 2000).

There has been steady increase in the potential for virtual techniques for many training applications. In particular, the ability to provide cost-effective access to high fidelity computer simulations is a very important attribute. VR has a proven influence on training processes by providing training establishments with a powerful new approach to training and research. VR provides access to sophisticated chemical plant facilities in a virtual format. The exact form of virtual training aids depends very much on the nature of the training program to be delivered. A broad spectrum of technology-based concepts are available, and it is extremely important to understand where and how to apply these to achieve an effective training medium (Kalawsky, 2000).

3.3.1 Types of virtual reality systems

Types of virtual reality systems are based on the mode in which they are interfaced to the users (Hitchner, 1995).

3.3.1.1 Immersive VR systems

The immersive reality system is the leading head-mounted VR display system that allows individual users to immerse themselves fully in the virtual environment through 3D imagery involving sight and motion. The user can navigate in the environment simply by hand and head movements.

3.3.1.2 Projection VR systems

Projection VR systems are a variation of the immersive systems, and they use single or multiple projection displays to create a room in which the viewer is able to stand or sit. The use of multiple projection-based systems can have a significant cost but result in high-resolution images being produced.

3.3.1.3 Desktop VR systems

Desktop VR systems are the most popular type of virtual systems and are based upon the concept that the potential user interacts with the computer

screen without being fully immersed and surrounded by the computer-generated environment.

3.3.2 Advantages of virtual reality

There are many areas where virtual reality could be used to support training. The benefits of VR training compared to traditional methods of training can be summarised in the following section:

Most people learn faster by 'doing', and virtual reality systems provide much greater levels of interactivity than other computer-based systems. Provided that the interfaces are intuitive and easy to use, the degree of interactivity can be very beneficial (Kalawsky et al., 2000).

The sense of immersion is a powerful characteristic in the field of engineering design, and the VR environment provides that. For example, architecture is an area in which the sense of scale is required to visualise the impact of a building design on the surrounding environment and the habitants. It is obvious that virtual reality systems are able to provide rescaling in three-dimensional designs, which is extremely important for engineering (Kalawsky, 2000).

VR training systems are powerful engineering tools because anyone can learn to use most of the interfaces in very little time and can become quite proficient under half an hour. They often provide an intuitive interface that can give access to vast quantities of data at a glance (Fluor Daniel Ltd., 1998).

The trainees can be anywhere in the world. Using telecommunications facilities, remote workers can work together in the same virtual area, on a chemical plant or a building site for example, even though they may be physically a great distance apart. As a result, travel costs could be reduced, and interactive programs with multiple sites networked for group learning and communication could be developed (IMO, 1998; Warwick, 1993).

VR training systems can allow trainees to experience unusual or potentially dangerous occurrences from a position of safety. Conventional training must

be very careful when putting trainees into situations, which could be hazardous. An example might be brake failure or a potential derailment situation (Vince, 1995).

3.3.3 Virtual reality applications

Application areas for virtual reality vary from game to construction industry and from military to surgery. Here is the short description of the application area of virtual reality.

3.3.3.1 Architecture

One of the most obvious applications of VR is the architectural walkthrough. Architects use graphic methods to lay out floor plans that show the positioning of rooms, doors, windows, and other building features as shown in figure 3.9. Realistic displays of architectural designs permit both architects and their clients to study the appearance of a single building or a group of buildings. Architecture uses VR to let the user explore a 3D scene in real time, showing exactly what the user wants to see, on demand, without having previously computed it. The real-time aspect of such systems is particularly useful to users, as it is enables them to show their design in much more detail and with greater realism.

Figure 3.9: Architecture walkthrough of a studio (after Cox, 2003)

3.3.3.2 Entertainment

A major use of VR is found in the entertainment market. This is, in fact, the biggest application in terms of financial profitability. Many companies are producing games that use VR principles. The audience for such games is enormous, making the games industry a key player in pushing software development. The gaming industry has a big impact on the VR field. It generates the necessary momentum in the industry to accelerate the development of a great variety of VR hardware, such as graphic accelerator cards. If we go back to a few years in time, it was difficult to find a graphic accelerator card having sufficient computing power to enable the creation of real-time VR applications. Other hardware devices such as VR gloves and head-mounted displays (HMDs) were partially influenced by the entertainment industry as well. An example for simulation game is shown in figure 3.10 (Cox, 2003).
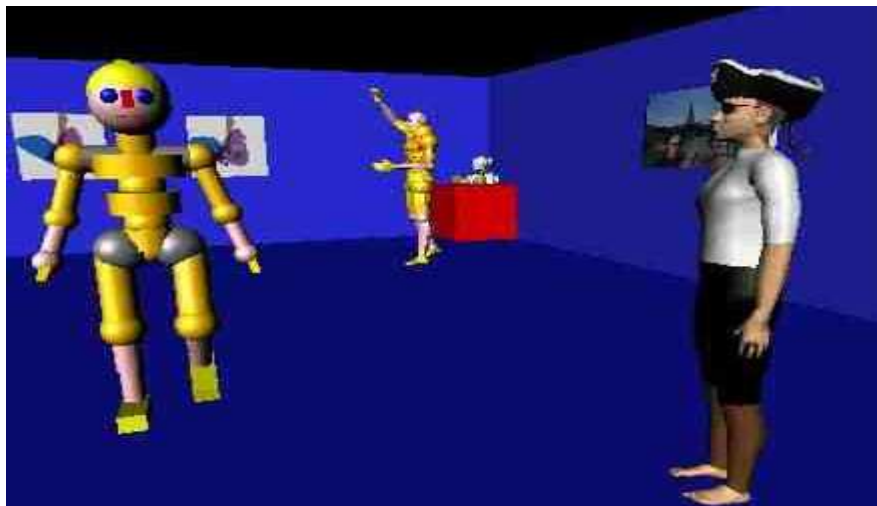
Figure 3.10: The use of virtual reality in game designing (after Cox, 2003)

3.3.3.3 Training

Virtual reality is a powerful tool for training because people comprehend images much faster than they grasp lines of text or columns of numbers. Many industries have produced virtual reality training simulators, which are used for planes, submarines, power plants, tanks, helicopters, ships, trains, surgery, and air traffic control. VR systems have the flexibility to structure different training scenarios, and they can monitor and measure the progress of every training session (Vince, 1995).

Virtual reality training through simulation provides significant benefits over other methods because the simulators allow the trainees to make mistakes and have the opportunity to experience first hand why certain procedures must not be used in the real world. Virtual reality training systems also have the flexibility to structure different training scenarios, and they can monitor and measure the progress of every training session.

3.3.3.4 Aircraft and vehicle training

This category of virtual reality application is concerned with creating a virtual environment that replicates all or some of the feature involved in the operation of a vehicle or an aircraft. The real control components can be integrated within the virtual environment, giving a realistic training experience. Pilots or drivers can experience the virtual reality simulation training systems without causing any harm to the vehicle, aircraft, or themselves (Carr, 1992).

At the Defence Helicopter Flying School (DHFS) at Shawbury, operators use virtual reality flight simulators to train United Kingdom Royal Air Force pilots. These VR training systems replicate in-flight conditions that are crucial to effective pilot training and realistically simulate scenarios including fog, rain, and snow; pilots are able to virtually experience reality before they ever leave the ground (FBS Ltd, 2001). A screenshot from such a flight simulator is shown in figure 3.11.

3.3.3.5 Medical training

Medicine has become a computer-integrated, high-technology industry. Virtual reality may have much to offer with its human computer interfaces, three-dimensional visualisation, and modelling tools. Advanced three-dimensional modelling tools can be used to develop useful models of the human body and in the design of artificial organs. Medical professionals can use virtual reality to study the body by navigating in and around it. A virtual reality technique could allow surgeons to conduct robotic surgery from anywhere in the world, offering increased accessibility to specialists. Prototypes have been tested that let the surgeons experience all the sensory

feedback and motor control that would be felt in person (Dutton, 1992; Nilan, 1993).

Figure 3.11: Screenshot from a flight simulator (after FBS Ltd., 2001)

3.3.4 Evaluation of virtual reality training applications

There are very few examples of evaluation studies in industry. Evaluation is concerned with gathering data about the usability of a design or a product by a specified group of users for a particular activity within a specified environment or work context. The evaluation of training is closely linked to the development process of training and is ultimately concerned with measuring how well the training achieved the objectives, defined in terms of efficiency and effectiveness. The evaluation of training can help improve the quality of training when the training method may be an old approach that needs modifications. In this way, the evaluation meshes closely with design and guides the design of the training system by providing feedback (Squelch, 1998).

Virtual reality technology has been investigated for application in the South African mining industry to provide improved hazard identification training for underground workers. This virtual reality model has been tested by a group of underground workers, and a series of evaluation trials was conducted at Elandsrand Gold Mine Training Centre in South Africa. These trials consisted of preliminary evaluation interviews during the development phase and a final, detailed evaluation of the virtual reality simulator and classroom

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training sessions. The results showed an encouragingly high level of acceptance and understanding of the virtual reality mine training simulator by the group of underground workers. The detailed evaluation confirmed that the application of virtual reality has relevance and potential in the field of mine hazard identification. Aspects found to be particularly favourable were the interactive and practical 'hands-on' nature of the virtual reality system, an acceptable level of realism of the visuals and sounds, and the implied message that mine management is treating the workforce with more respect (Squelch, 1998).

3.3.4.1 Landfill site

A research group from the University of Nottingham developed a virtual environment training application for landfill site inspection. The virtual reality system was used for training site inspectors to perform an environmental audit of a landfill site. The trainee's task was to go around the virtual landfill site, spotting and identifying all the safety hazards within the site. Figure 3.12 shows a still from the virtual landfill site application.

Figure 3.12: Virtual landfill site (after Rajarathnam, 2000)

Twenty-seven undergraduates in their second or third year, majoring in environmental engineering, originally took part in a series of evaluation trials of this virtual reality training system. In the first part of the experiment, the trainees watched a video, which was produced by accompanying an expert navigating the virtual landfill site, spotting and identifying hazards. In the

second part of experiment, each of the subjects used the virtual reality training system, and for 20 minutes, they tried to spot all the hazards that were present in the virtual landfill site. The results of this experiment showed that virtual reality training was more effective than video training. Subjects mentioned that the virtual reality training system had made hazard spotting easy, and it had helped them learn and understand issues related to environmental safety in a landfill site (Rajarathnam, 2000).

3.3.5 Virtual safety training in chemical engineering laboratory

A virtual environment was created for the absorption column situated at the chemical engineering laboratory at the University of Nottingham. The environment focused primarily on training and safety issues for students using the equipment. The dynamic features of the virtual absorption column simulation gave a level of realism in the virtual environment. Nasios (2001) believes that this helps the students to gain a deep understanding of the chemical engineering principles that govern this mass transfer process. The virtual plant operates in real time; the students have to monitor instrumentation and wait until the equipment reaches its steady state condition shown, as in figure 3.14.

Simple evaluation trials were carried out for the virtual flooding and gas absorption experiment.

Figure 3.13: Virtual absorption column

Figure 3.13 shows a general view of the virtual reality absorption column experiment (Nasios, 2001) that produced encouraging feedback indicating the suitability of applied virtual reality technology and concepts. These trials provided useful comments for incorrect and missing components and confirmed the hypothesis that virtual reality has relevance and potential in the field of chemical engineering. Trainees found particular favour with the interactive and practical 'hands-on' nature of the virtual reality system, acceptable realism of visuals and sounds, and the dynamic simulation of the chemical process. The use of the joystick provided some initial difficulty in the use of virtual reality system, but this was limited to only a few of the subjects. The majority of users said that they required more time to become familiar with the device and the virtual reality system, which is not unreasonable to expect.

3.4 Summary

VR training systems can allow trainees to experience unusual or potentially dangerous occurrences from a position of safety. Conventional training must be very careful when putting trainees into situations that could be hazardous. The virtual reality concept of allowing the user to interact directly with the virtual world has made training and education easier. Virtual reality is a widely useful tool for chemical industrial safety and training.

This research follows Nasios's research to design a virtual reality model for an adsorption column at the chemical engineering laboratory at the University of Nottingham. Later, his research a VLE model was developed for the bubble cap distillation column at the chemical engineering laboratory at the University or Nottingham. The research work has extended to use VLE for promoting constructivism in the chemical engineering laboratory safety and hazard awareness.

The research presented in this thesis extends research in the application of the virtual reality models as presented by Nasios (2001). Although his work developed an adsorption column at the chemical engineering laboratory at the

University of Nottingham, he completed a VLE model but did not extend this to work as a learning aid. For the current research, a VLE model was developed for the bubble cap distillation column at the chemical engineering laboratory at the University of Nottingham. The research has extended the use of VLE to promote constructivism in the chemical engineering laboratory safety and hazard awareness training.

Chapter Four

Literature Review III

Learning Technology

4.1 Introduction

This chapter reviews the available literature relating to the learning technologies. It also describes the types of the learning technologies with their applications and evaluations.

4.2 Definition and types of learning technology

Learning technology is defined as the application of technology for the enhancement of teaching, learning, and assessment. Learning technology includes computer-based learning and multimedia materials and the use of networks and communications systems to support learning. The following categories indicate the main application areas for learning technology (Roger et al., 1999).

4.2.1 Drill and practice package

Drill programs provide extensive opportunities for practising well-defined skills. Drills assume that information has already been taught and that it now needs to be reinforced. Much of what has been learnt requires reinforcement and practise before it automatically becomes part of the way to do things.

Computer-aided drill instructions provide continuous practice of clearly defined skills. The learner is given immediate feedback, and, when responses are inaccurate, corrective action is immediately introduced. This process can be repeated until an appropriate level has been reached. This repetitive process must be designed in such a way to reduce the boredom that most of the learners suffer with mindless repetition. Generally, such drills have only a limited application. The purpose of drills is to provide efficient practice once the initial instruction has been given. Drills can be used in a wide variety of environments, for example, music, learning vocabulary of new language,

arithmetic, problem solving in mathematics, and in the physical and social sciences.

4.2.2 Tutorials

Tutorials are used to teach new concepts and processes. Material is presented to the student in a structured format. Tutorial software usually includes worked examples and gives the learner the opportunity to assess understanding with questions, answers, and feedback. Intelligent tutoring systems are capable of corrective feedback and adjust their presentation to suit the learner, based on the actions of the learner (O'Brien, 1994).

Tutorials, when designed effectively, can model the very best in teaching techniques. Tutorials can teach information, verify information, and highlight information through a process of interaction with the computer. Tutorials are best used to present new information (concepts and skills) from students to students. In many cases, instruction is designed to be self-contained so that the student will have been carefully informed regarding the skills of knowledge (O'Brien, 1994).

An example of computer learning tutorials is the self- paced online learning tutorial. This is an interactive approach for delivering content to the students. Hands-on practice, interactive content, assessments, step-by-step video with audio, and other features make online learning effective. There is no need for travelling offsite to attend classes, as the online computer tutorial programs are available 24 hours a day and seven days a week.

4.2.3 *Information retrieval systems*

Information retrieval systems store knowledge in a structured way and allowed the learner to browse or search for information as required. They include on-line databases and structured information systems such as dictionaries, encyclopaedias, hypertext, and hypermedia reference systems.

4.2.4 Simulations

Simulations are powerful techniques, which duplicate or reproduce complex, real-life situations. Learners learn about the real world using the techniques.

Learning is made easier because simulations often simplify reality or they make learning more cost effective and safe. The major implication for learning with simulations is that the learner actually performs activities similar to those in reality.

Simulations can be divided into two main groups: those that teach about something and those that how to do something. Simulations that teach how to do something are classified either as procedural or situational simulations. Those that teach about something are classified either as physical or process simulations (Bhaskar et al., 1990).

Situational simulations deal with attitudes and behaviours of people in different situations. This type of simulation allows the learner to explore the effects of different approaches to solving a problem. The learner plays the major role in solving the problem.

Physical simulations present a physical object or phenomenon on the computer screen, giving the learner an opportunity to learn about it. An example is the observation of molecules under the influences of temperature and pressure. The learner is able to manipulate irrelevant variables to see effect. This type of simulation presents opportunities for the learner, which would not normally be available. Time and size do not limit the capabilities of the simulation.

Process simulations also teach about something. They are normally used to demonstrate processes that are not clearly visible, such as the economic law of supply and demand and how populations grow and decline. Process simulations are used for forecasting these types of situations. They are useful because they can also accelerate or slow down these processes.

4.2.4 Microworlds
Microworlds use the computer to create a problem-solving environment. They are derived from the work of the cognitive psychologist Jean Piaget. Seymour Papert, for example, introduced the Logo language into schools to encourage children to learn about mathematics (Roger et al., 1999).

4.2.5 Cognitive tools for learning

Cognitive tools for learning are based on the constructivist principle, which states that learners need to construct their own understanding of new concepts. These tools give the learner a way (often graphical) of representing their understanding of new knowledge and concepts. Expert systems and authoring tools can also be used in this way, allowing the learner to present his or her understanding in a way that can be accessed by other learners. To take notes when students are attending class is the example of the cognitive tools, as the learner can create his or her own understanding from the lectures (Marton et al., 1976).

4.2.6 Productivity Tools

Productivity tools include applications such as word processors, spreadsheets, databases, graphics, desktops, and publishing and presentation packages. Whilst these tools are not specific to learning technology, if they are to be used within a pedagogical framework, they can support learning by enhancing the quality of the learning process. They also support learning by encouraging drafting, reflection, and editing and they remove from the student the assignment of having to rewrite any written submission. Spreadsheets can promote a structured approach to problem solving and enable the student to spend more time on the task at hand rather than on routine or lengthy calculations. Databases can be used to help students as well as staff to organise information related to their courses and to develop their information-handling skills (Roger et al., 1999).

Presentation packages provide much the same benefits for spoken presentations as the graphics and desktop publishing packages do for written ones. They are clearly of great benefit to support conventional lectures, enabling the lecturer to draw together text and graphics. They are equally helpful in enabling students to demonstrate their understanding of new knowledge and its applications, supporting them in the development of oral presentation skills.

4.2.7 Communication tools

Computer-generated communication takes several forms, including electronic mail, electronic conferencing, video conferencing, and the World Wide Web. These tools allow learners to share ideas and information, to co-operate, and to collaborate on joint work, and they can also be used for submission and publication of students' assignments and of tutors' comments on students' work.

Electronic mail (e-mail) is the type of communications medium that does not require the recipient of a message to be coordinated in time or place with the sender. E-mail can be used one-to-many as well as one-to-one. These characteristics are helpful in maintaining communications between tutor and student(s) and among students as they overcome limitations of distance and time.

Applications and evolutions of learning technologies

Here is the short description of the applications of the technologies for learning.

4.3.1 Visual learning

Visual learning can be defined as the "ability to construct meaning from visual images" (Giorgis et al., 1999). To make meaning from images, the 'reader' uses the critical skills of exploration, critique, and reflection. Images can be very powerful. Visual learning involves problem solving and critical thinking.

Software such as Adobe's image production suite, including Photoshop, Photoshop Elements, and Premiere, makes the production and distribution of images extremely easy. It is now cheap and easy to create full-colour and animated visual images. The creation of images that were previously only the domain of professional artists and filmmakers is now available for anyone. Visuals, including animation, film, and 3D virtual reality, enable intelligent and interactive communication through all the senses (Bamford et al., 2003).

Television is a form of visual communication that enables on-the-spot, live pictures to be presented directly in the home, school, university, or factory. By means of television, millions all over the world may see and hear the events of daily life as they occur and to profit from the mass broadcasting of knowledge and culture (Korte, 1967).

4.3.1.1 Evolution of visual learning

Rather than going to the country itself, which many of the learners may never do, there is no better way of seeing its geography, history, and social life—with television. In addition to this cultural background, one can also see the speakers and learn to use what we see to help understand what is being said; are the speakers smiling, making angry gestures, or signalling their shoulders? Television is often recorded on location, which can provide the viewer a range of regional accents with the television material (Turker et al., 2005).

There are many reasons for using recorded television programmes regularly in today's learning. They provide variety, of course, and supplement the range of material. The BBC and Channel 4 produce a wealth of regularly updated programmes targeted at particular learners (adults and school learners from primary to advanced levels). The material is often closely linked to the sorts of topics that a school must cover for the National Curriculum. Generally, it presents in action of some of the vocabulary and structures specified in examination syllabi. Furthermore, it often comes with transcripts and ideas for development. Details of programmes can be found for the BBC at www.bbc.co.uk/languages and for Channel 4 at www.channel4com/mailn/secondary/modlang.htm (accessed on 15 July 2007).

4.4.2 Computer-based learning

Computer-based learning has expanded into many different levels and forms. It is used in all levels of education, from elementary to graduate school. Some computer-based programs are offered in an actual classroom facilitated by a teacher. In these more advanced forms of computer-based learning, many students may never even meet their instructor in person (Ranson et al., 1996).

4.4.2.1 Evolution of computer-based learning

Kekkonen-Moneta and Moneta (2001) compared the learning experience and the learning results of college students. The students were studying a course on computing fundamentals. One group (105 students) studied through lectures, and the other (180 students) studied with an online course. Both groups had weekly laboratory sessions with a teaching assistant. The assessment was based on a mid-term examination. The examination included multiple-choice questions for testing students' learning and questions for estimating the students' IT skills. Overall, 261 students participated in this study. This study showed no differences in learning or satisfaction between these two groups. The students in the lecture course performed in the conceptual questions better than students in the online course. However, students taking the online course believed the course to be less difficult than students on the lecture course.

Zhang et al., (2004) conducted two experiments in which they compared a prototype of a virtual mentor (VM) system called "Learning by Asking" (LBA) with traditional classroom teaching. All together, 52 students participated in the e-learning group, and 51 students stayed in the traditional classroom group. All participants were undergraduate students. The same instructors taught both groups and ensured that the material was the same for both groups. The effectiveness of learning was measured by test grades (objective approach) and questionnaires (subjective approach). In this experiment, the students in the e-learning environment earned significantly higher grades than those in the traditional classroom situation. However, in this case, the satisfaction level between the groups did not differ significantly.

McDonald et al. (2004) compared students' performance in a traditional classroom and in an online course. The data was collected over a period of two years. The data included students' final grades from a specific course and information on students' overall performance at the university. In the traditional classroom group, there were 134 students, and in the online group, 63 students. The results showed that students who studied in the traditional classroom performed better than the online students. It was discussed whether

one reason for this could be the long history of using traditional lecturing at the university. Also, the development of a good online course takes time.

Game learning

Prensky (2001) has defined a game as a subset of both play and fun. Prensky recognises a game as organised play that gives enjoyment and pleasure. Dempsey et al. (1996) define a game as a set of activities involving one or more players. It has goals, restrictions, payoffs, and penalties. A game is rule-guided and artificial in some respects. Finally, a game involves some aspect of competition, even if that competition is with oneself. Competitive games may involve taking chances in an imaginary setting. They motivate via challenge, fantasy, and curiosity (Randel et al., 1992).

Prensky (2001) states that computer games can be characterised by six key structural elements, which, when combined, strongly engage the player. These elements are

- Rules
- Conflict/competition/challenge/opposition
- Goals and objectives
- Interaction
- Outcomes and feedback
- Representation or story

Fabricatore (2000) stated that, for video games, there are two key elements that differentiate them (although this distinction is not exclusive). These are as follows:

(i) Videogames include an interactive virtual playing environment.
(ii) In videogames, the player has to struggle against some kind of opposition.

Many good video games come with free software on the disk that contains the game; the software allows players to build new extensions to the game or even new games altogether (Prensky 2001). Game play can be competitive, cooperative, or individualistic (Becta, 2001). Game types include educational

games, adventure games, or simulation games, as discussed here with relevant examples.

4.3.3.1 Educational games

Many educational games are simply drill-and-practice programs that have the added interest of (for example) a competitive edge, such as beating the clock, or a goal, such as building a wall on the screen or climbing out of a deep cave. Such games can be use to develop skills, a concept, or recall of factual knowledge.

One of the American game developing groups, the Thiagi group (discussed in section 2.2.4.5), has developed a range of more than 150 ready-to-use online learning games and activities to engage participants. Some of them are as follows:

2-Minute Drill: This game combines the effective organisation of well-written documents with the motivational impact of learning games. Participants read a handout, booklet, reprint, or a chapter in a book and play a game that uses peer pressure and peer support to encourage the recall and transfer of what they read. From 12–25 participants are organised into groups of four or five. The time required is 15–30 minutes. Materials required are reading materials such as books and brochures and question cards, where each card contains a short answer about the training content. Normally, 20–100 different questions are needed as well as an answer sheet with the question numbers, correct answer for each question, and instructions on how to play the game.

4.3.3.2 Adventure games

Adventure games involve placing the learner in an imaginary situation, for example, on an ocean with pirate and treasure ships, in the land of the Hobbit, or inside a secret garden. This type of adventure games includes the use of text, graphics (3D), character graphics, bitmap graphics, sound (music), and video clips. An example of the 3D game is *The Pandora Directive,* which was written in 1996 by Chris Hones and Aaron Corner. It has two different game levels (entertainment and game players), three different paths (Mission Street,

Lombard Street, Boulevard of Broken Dreams; which path one follows depends of certain decisions the takes in a certain time), and six endings. Instructions should be given to the user (or users) to do certain things or make certain moves. Children using the adventure game can choose their own route and skills (e.g., the use of coordinates and direction finding) to encourage 'interaction' between computer and user and discussion amongst the children using the program.

4.3.3.3 Simulation games

Simulation games are one of the most popular types of games. Here, participants are provided with a simulated environment in which to play (Cruickshank, 1980). Simulations are also defined as the products that result when one creates the appearance or effect of something else (Laurel, 1991). Simulation games are ideal for generating discussion and encouraging decision making, but genuine simulations go slightly further by developing learning by discovery. Simulations are based on a model of a situation, usually real but sometimes imaginary. A model can be defined as a simplified representation. In a simulation, the model is ready created by the programmer.

A UK study concluded that simulation and adventure games such as *SimCity* and *RollerCoaster Tycoon*, in which players create societies or build theme parks, develop children's strategic thinking and planning skills. Parents and teachers also believe their children's mathematics, reading, and spelling improves (McFarlane, 2002).

4.3.3.4 Evaluation of game learning

One of the games developed by MIT Games-to-Teach seeks to further explore the development of 'enlarged reality education gaming'. The game builds on developments in handheld gaming, where context-sensitive data and social interactions are used to supplement real-world interactions. The goal of the Environmental Detectives game is to teach secondary school and first-year undergraduate students the skills of environmental inquiry by using a simulated environmental problem. Through collaboration with environmental engineers, a scenario was built around a spill of a toxin called Tri-Chloro-

Ethelene, which is a groundwater contaminant with moderate long-term health effects. The game included functionality to support the collection of both primary data (raw data on contamination levels acquired by sampling) and secondary data (interviews with 'virtual' experts) (Naismith, 2004).

The game was location based, with the 'virtual' activities only being available in certain 'physical' locations, as detected by a module attached to the Pocket PC. The interface was primarily map based, and students worked in pairs to navigate through the physical space to get to the virtual information. The goal of the game was to discover the source of the contamination and to prepare a suitable plan. The students were required to make tradeoffs between seeking interviews and drilling a well to sample ground water, mimicking the real challenges encountered in environmental investigations.

Five trials were conducted, with game play lasting between 90 minutes and two hours. Most groups were able to either locate the general area of the toxin or some basic remediation strategies. However, a few groups had fully logical solutions. The secondary school students had particular difficulties with the details of the investigation, indicating the need for additional scaffolding. Students responded very favourably to both the investigative experience and the experience of interacting with the technology. The researchers have designed a tool kit for implementing customised scenarios, available through the Games-to-Teach Web site at http://www.educationarcade.org/gtt/Hand-held/Intro.htm (accessed 19 June 2007).

4.3.4 *Mobile learning*

With respect to technologies, 'mobile' generally means portable and personal, like a mobile phone. Many examples of learning with mobile technologies fit in this description. Personal digital assistants (PDAs) and mobile phones are the most commonly used technologies for mobile learning.

'Mobile learning' is both a new concept and one that has some familiar implications. It is certainly concerned with learner mobility, in the sense that learners should be able to engage in educational activities without the

constraints of having to do so in a tightly delimited physical location. 'Mobile learning' comes with the possibilities opened up by portable, lightweight devices that are sometimes small enough to fit in a pocket or in the palm of one's hand. Typical examples are mobile phones, smart phones, palmtops, handheld computers (PDAs), tablet PCs, laptop computers, and personal media players. These devices can be carried around with relative ease and can be used for communication and collaboration and for teaching and learning activities that are different from what is possible with other media (Kukulska-Hulme, 2005). According to O'Malley et al. (2003), mobile learning is taking place when the learner is not at a fixed, predetermined location or when the learner takes advantage of the learning opportunities offered by mobile technologies.

Increasing use of mobile devices and of handheld games such as the *Game Boy Advance* offers opportunities for developing educational software to support combined learning. For example, classroom-based learning can e linked to learning online and/or outdoor activities such as museum visits and field trips (Kirriemuir, 2002).

4.3.4.1 Evolution of mobile learning
Researchers at the University of Birmingham (UK) have developed and trailed a mobile learning organiser based on a wirelessly-enabled pocket PC, with master's-level students in 2002–2003, to determine the key tools necessary for such a learning device (Holme and Sharples, 2002; Sharples et al., 2003; Corlett et al., 2004). The Student Learning Organiser is an integrated suite of software tools developed at the University of Birmingham. The 'Time Manager' tool includes the ability to create, delete, and view timetable events and deadlines, while the 'Course Manager' tool allows students to wirelessly download course material packages, created by a complementary desktop tool, in Microsoft Reader format.

A one-year trial was conducted with 17 MSc students in the Department of Electronic, Electrical, and Computer Engineering. Each student was given a Compaq iPAQ 3760 Pocket PC 2002 handheld with 64MB of memory. As

devices with integrated wireless capabilities were not available at the time, it was necessary to provide each student with an expansion sleeve and an 802.11b wireless network card. In addition to the Student Learning Organiser tools, the students had access to cut-down versions of Microsoft Word, Excel, Outlook, Internet Explorer, Media Player, e-mail, instant messaging, and two concept-mapping tools. The students were encouraged to use the handhelds for their personal activities and to install additional software as they wished.

Results were collected via questionnaires, focus groups, video recordings, and logbooks. Communication tools and time-tabling features were consistently rated by the students to be the most useful, while the course content and concept mapping tools showed a trend of decreasing usefulness over time. Little additional software was installed with the main reasons being that students saw the value of the handhelds being in the time management of e-mail/messaging applications provided. Also, students were unwilling to invest time and money in personalising a device they had to return at the end of the year.

4.3.5 Virtual learning environment (VLE)

A virtual learning environment (VLE) represents an entirely new form of educational technology. A VLE is a set of teaching and learning tools designed to enhance a student's learning by including computers and the Internet in the learning process (Everett et al., 2002). A VLE may support forms of learning similar to 'real' ones, but it is not a physical space like a classroom or a lecture theatre. Learners may work closely together while not being active at the same time (Picciano, 2001). A VLE can be used to supplement traditional instruction, which will improve student achievement (Lorenzetti, 2003). Students hesitant to speak in class may be proactive in the threaded discussions of a VLE when the audience is removed (Fryer, 2002). This leads to a greater depth of learning and engagement for many students.

Follows (1999), a professor and director of the Acadia Centre for VLE at Acadia University, listed benefits in using a VLE for post-secondary student use. For the high school experience, VLEs provide the student with the

framework of the learning process to take place. The VLE can be used for further understanding of a concept and making the concept more concrete and real to the learning. VLEs allow the student to control the learning process.

4.3.5.1 Advantages of the virtual learning environment

Many studies report that the virtual learning environment is more effective, efficient, and satisfying than the traditional learning situation. In recent years, several case studies (Piccoli et al., 2001) have dealt with the use of VLEs in teaching information and communication technology (ICT). VLEs have advantages compared with traditional teaching. When different lecturers lecture on the same topic, no two lectures are ever exactly the same. Furthermore, the same lecturer hardly ever repeats the same lecture in exactly the same form or with exactly the same content (Walker & Harrington, 2004). Lecturers can demotivate students with their routines. On the other hand, VLEs are a flexible way of teaching (Walker & Harrington, 2004) because they can be used at the most convenient moment (Clarke, 2001). For example, the player can experience a role or roles in a real-life setting and, at the same time, learn about the setting itself, developing perceptive skills at coping in that environment (Khan, 2002).

Students do not have to follow a specific timetable, as they would have to do with traditional lectures, and therefore, they cannot miss a lecture (Walker & Harrington, 2004). Lee et al., (2002) found in their study that positive attitudes toward using computers were the key factor in the VLE's success. Students' positive relationships to computers also helped the learning process (Lee et al., 2002, Crosier et al., 2000).

4.3.5.2 Applications of the virtual learning environment

Virtu-VLE for safety at work: Ihamaki et al., (2004), have designed a virtual learning environment (VLE) concerning safety at work called Virtu (Figure 1). Virtu was developed in a cooperational project between the Institute of Occupational Safety Engineering and the Institute of Software Systems in Tampere University of Technology. In addition to more traditional VLE

content, such as theory and exercises, Virtu contains a virtual enterprise, which simulates a visit to a real company.

These design activities resulted in defining two main usage scenarios related to two main end user groups for Virtu. The first scenario is about teaching safety at work for students of Occupational Safety Engineering at TUT. The second scenario is testing and updating industrial workers' knowledge of safety issues related to their work. The Virtu user interface was designed by applying usability practices, including stakeholder and user interviews, prototyping, evaluation, iterative design, and user testing so that both end-user groups would find the environment interesting and easy to use (Preece et al., 2002).
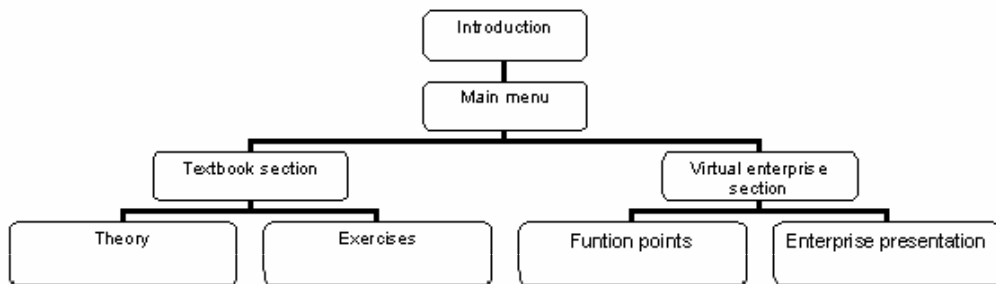
Figure 4.1 Structure of Virtu (after Ihamaki et al., 2004)

Virtu supports the constructivist learning model in which individuals are assumed to learn better when they discover things themselves (Ahmad et al., 1998).

VLE for library staff training: Moira Bent (2002), faculty liaison librarian at the University of Newcastle, has developed VLE software. Using a VLE as a training medium has the dual benefit of both delivering training via the VLE and enabling library staff to develop practical skills in the use and understanding of the VLE. The JISC (JISC, 2001) recommends that institutions should, 'where possible use the VLE software to provide staff training as it will encourage staff to reflect on the learning experience of using a VLE'. Whilst referring to training academic staff in the use of a VLE, it is equally applicable to libraries. Interestingly, the VLE software includes a table of VLE skills, which it recommends various groups of university staff should

have, and it appears that library staff need more skills than anyone except senior university managers.

Building on these principles, the staff development module at Newcastle University Library was introduced in January 2002 using Blackboard. It covers a wide range of topic areas, ranging from WWW use, to specific subject skills, personal skills, IT skills, health and safety, "hot topics," and many more (Bent, 2002). The staff in the library are registered on the staff development module as students and can access the materials either in time-tabled staff training time or in free time either at home or at work. The staff who are involved in delivering any kind of training to their colleagues become 'course builders' and are encouraged to add their own training materials and documentation to the module.

4.3.5.3 Evolution of the virtual learning environment

Piccoli et al. (2001), arranged an experiment that lasted one semester. The test conditions were perfect for enabling the use of statistical methods. A total of 146 undergraduate students participated in the experiment, which concerned a course in basic IT skills. The hypothesis that stated that students in the VLE would score higher points in the exam than the students in the traditional classroom was not supported by the findings. The VLE students outperformed the traditional classroom students, but the difference was not statistically significant. The hypothesis regarding a difference in satisfaction between the VLE group and the control group was correct. Surprisingly, the students in the VLE group were less satisfied.

Both VLE and VR are used in safety training. For example, Filigenzi et al., 2000; Harrington and Walker, 2004; and Walker and Harrington, 2004 have concluded that VLE is an effective safety training tool. Filigenzi et al., (2000) and Kizil and Joy (2001) have used VR for miners' safety training. After the training, students' ability to identify hazards had improved. They also concluded that VR technology improves miners' safety. Walker and Harrington (2004) compared the effects of CBT and instructor-led training in fire safety. They found that the computer-based group used less time than the

traditional lecture group for the training, and so the CBT might be more effective than traditional lecturing. Nevertheless, they were not able to change attitudes toward occupational safety using computer-based learning.

4.4 Summary

There are opportunities with new and emerging technologies for providing effective coaching in an adventure game environment. Students hesitant to speak in class may be more willing to do so in the discussions of a virtual learning environment, when the audience is removed. Virtual environments lead to a greater depth of learning and engagement for many students. Virtual learning environments are in keeping with the spirit of constructivism in which learners, teachers, and students are active participants of knowledge formation, not just the recipients of knowledge (Harrington, 2004).

Video games incorporate a powerful learning principle that fits well with inquiry-based classrooms and with workplaces that encourage workers to think proactively and critically to build new knowledge in practice for the business. However, this is done poorly with traditionalist, passive, skill-and-drill, school-based learning.

Chapter Five
Design of a Virtual Learning Experiment Model

5.1 Introduction

This chapter will describe the design of the virtual learning environments of a bubble cap distillation column. The virtual learning environments were based on an undergraduate laboratory experiment for the chemical engineering degree course at the University of Nottingham. The first section will discuss the design and construction of the model. The second section will discuss the laboratory procedure for the distillation process at the chemical engineering laboratory at the University of Nottingham. The final section will discuss the design of the virtual learning environments using the VLE model for the laboratory rig.

5.2 Development of the three-dimensional model

The three-dimensional model of the bubble cap distillation column was constructed using 3D Studio Max software. The type and the construction of the object is a fundamental issue in the development of the virtual reality training system. The total number of polygons was kept to a minimum, as this has an impact on the rendering speed of each frame. Objects needed to be constructed with an appropriate number of details so they would be easily recognisable. A high number of texture maps were used, and a suitable portion of carefully chosen and scanned-in photographs were obtained to bring a sense of reality to the virtual environment. This section describes the construction of the objects used to build the virtual environment.

5.2.1 Laboratory column stand

The construction of the stand, which would hold the column and the pipelines, was built from the real dimensions and photographs of the laboratory rig. The colours and the texture maps, which have been mapped on to the three-dimensional object, were manipulated using Adobe Photoshop software.

Figure 5.1 shows a perspective view from 3D Studio Max of the scaffolding object.
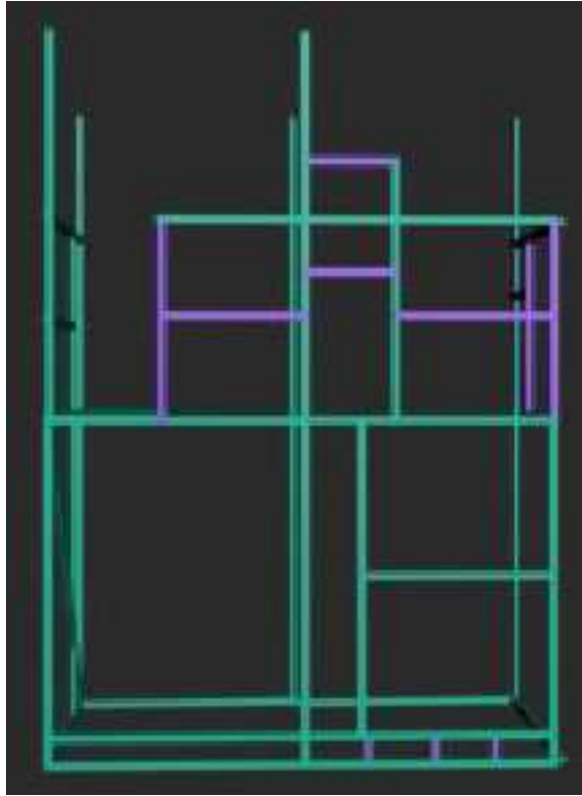
Figure 5.1 the prospective view of scaffolding of VLE model

5.2.2 Valves

A three-dimensional valve object constructed in 3D Studio Max contained too many polygons to be practical. To improve this problem, a simple shape containing only 140 polygons (shown in figure 5.2) has been used and was modified to reduce the number of polygons. No textures were required for this object. The shape containing 4320 polygons is very smooth; however, to maintain the lower polygon numbers, the shape with 140 polygons was selected to construct a valve in the VLE model. Figure 5.2 with the wireframe view and figure 5.3 show the perspective views of the same valve design.

| 4320 polygons | 1656 polygons | 140 polygons |
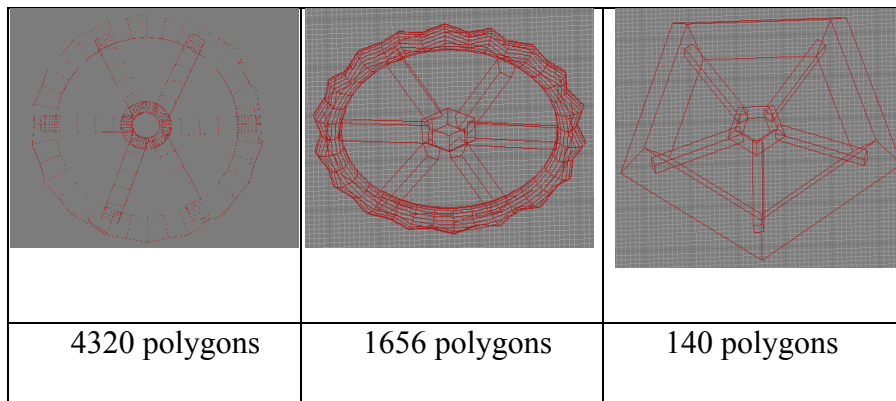
Figure 5.2: Wire frame view of the different shapes of the valves

| 4320 polygons | 1656 polygons | 140 polygons |
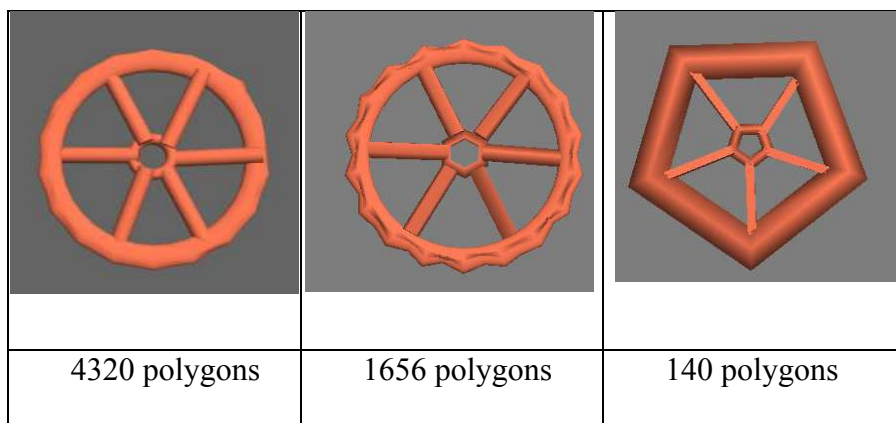
Figure 5.3: Perspective view of the different types of valves

5.2.3 Rotameter

A rotameter is a type of flow meter that consists of, essentially, a "float" that is free to move up and down in a vertical glass tube. There are two rotameters in this experiment that are used to measure the flow of gases and liquid streams.

The construction of digital measurement equipment such as the rotameter was considered complicated and difficult. First, it was necessary to keep the number of polygons as low as possible. Second, designing the moving float in a glass tube led to the design of a transparent rectangle with a box object inside, which is finally animated to move up and down to simulate the flow of the fluid shown in figure 5.4.

Float	Float

(i) Image of front view of the laboratory rotameter

(ii) Perspective view of the VLE model
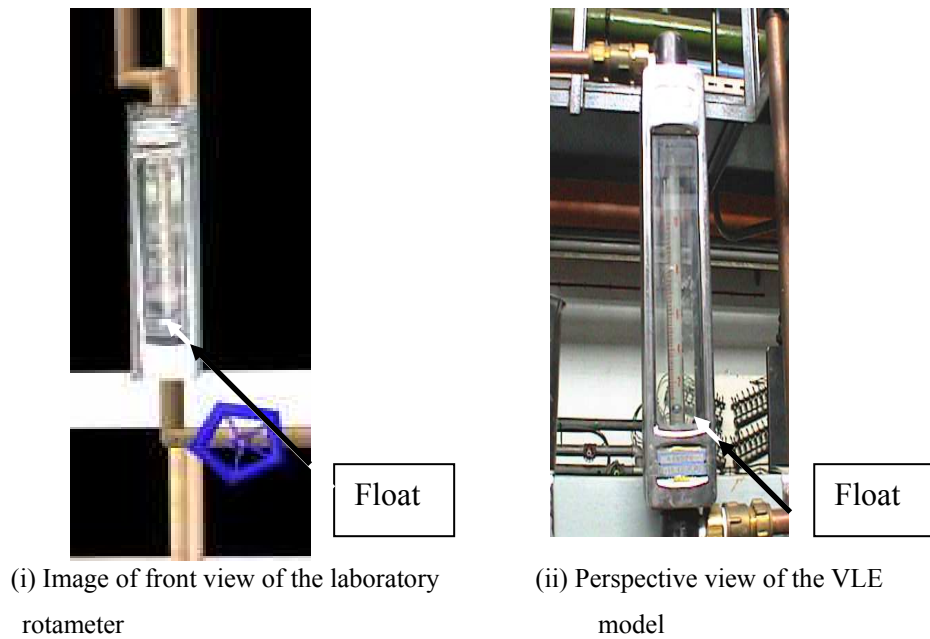
Figure 5.4

5.2.4 Pressure bar

It was necessary to keep the number of polygons to a minimum because of this digital equipment. For that reason ,a six-sided cylinder with an arrow-shaped object on its plate was designed to represent pressure meters. Figure 5.5(i) shows the image of laboratory pressure bar, which was used to design the pressure bar in the VLE model in figure 5.5(ii).

(i)   (ii)
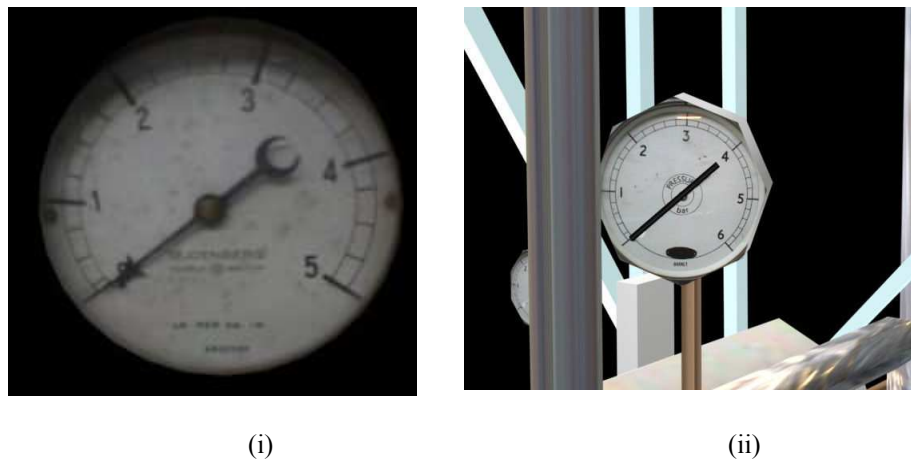
Figure 5.5 (i) Photograph of laboratory pressure bar and (ii) perspective view of pressure bar

5.2.5 Pipes

Most of the pipes were made of six-cylinder objects in 3D Studio Max. Figure 5.6(ii) shows a perspective view of the pipelines designed for the VLE model.

An example of the texture map, which was applied to a cylinder, is shown in figure 5.6(i).

<div align="center">(i)   (ii)</div>
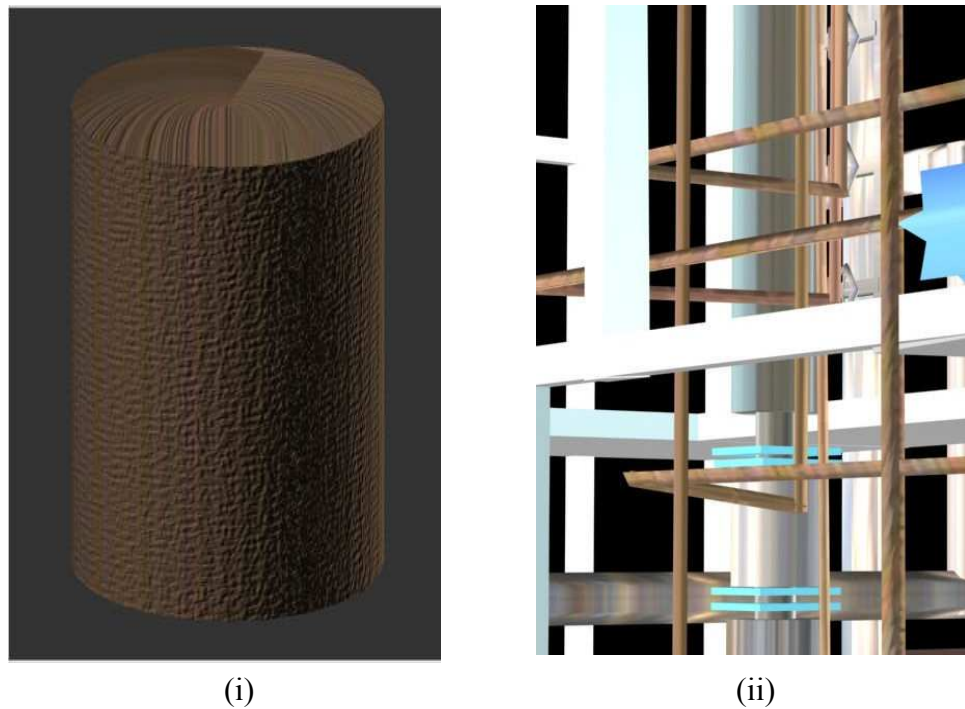
Figure 5.6: (i) Texture map and (ii) prospective view of pipes

5.2.6 Taps

Taps are located on the main column where distillation takes place. The main purpose is to take samples of the process at regular intervals. The design of the taps was tricky. To maintain the low number of polygons, taps were designed using simple boxes and were joined as shown in figure 5.7(ii). An image of the texture applied is shown by figure 5.7(i).

<div align="center">(i)   (ii)</div>
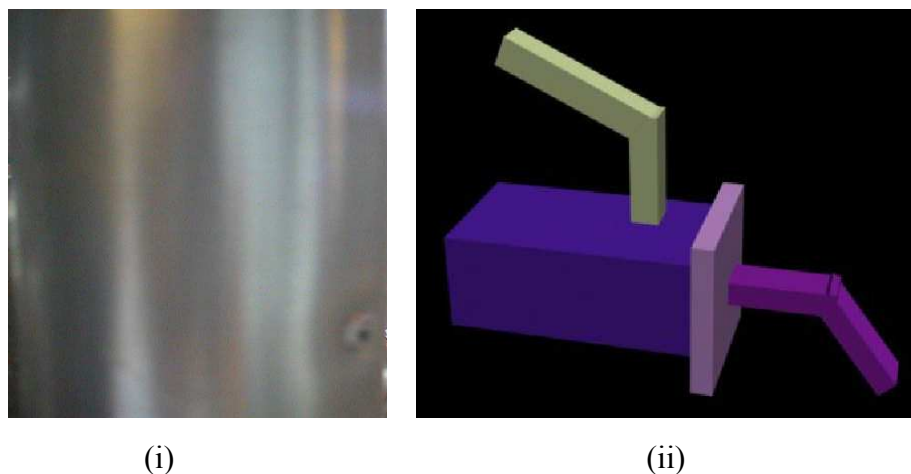
Figure 5.7 (i) Texture map of tap and (ii) perspective view of tap

5.3 Laboratory experiment setup and procedure

During the laboratory hour, different types of experiments are carried out. The first year students' modules are limited to the introduction of the column as a subject. Second-year degree students perform experiments to find the column efficiency. Final year-degree students perform and find different ways to maximise efficiency of the column. The aspects of the laboratory hours as the introduction include the awareness of

(i)   a preliminary check before starting the operation.

(ii)   start-up and shut-down processes.

(iii)   control of the process using different valves.

(iv)   hazard and safety aspects of operating the rig.

The standard procedure of the laboratory rig as per the laboratory manual is described here (updated June 2007). The positions of valves A (feed), B (steam), and F (boiler level) are labelled in figure 5.8. The photograph is a part of the laboratory manual of the Chemical Engineering Laboratory at the University of Nottingham. Here is the short description of the laboratory experiment.
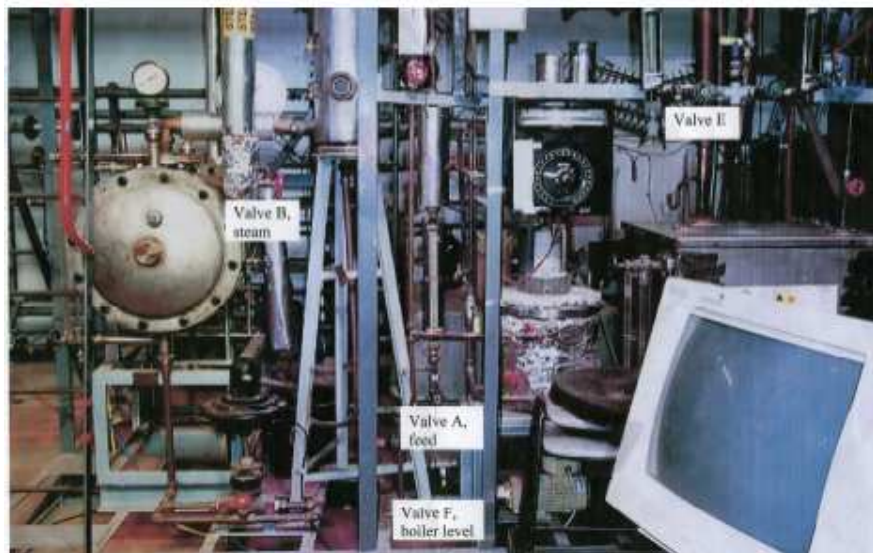
Figure 5.8: Laboratory experiment photograph (laboratory manual at the University of Nottingham)

5.3.1 Problem

The objective was to study the performance of a bubble cap distillation column producing high purity methanol continuously from a methanol/water mixture and to determine the effects of reflux ratio and feed rate on the column.
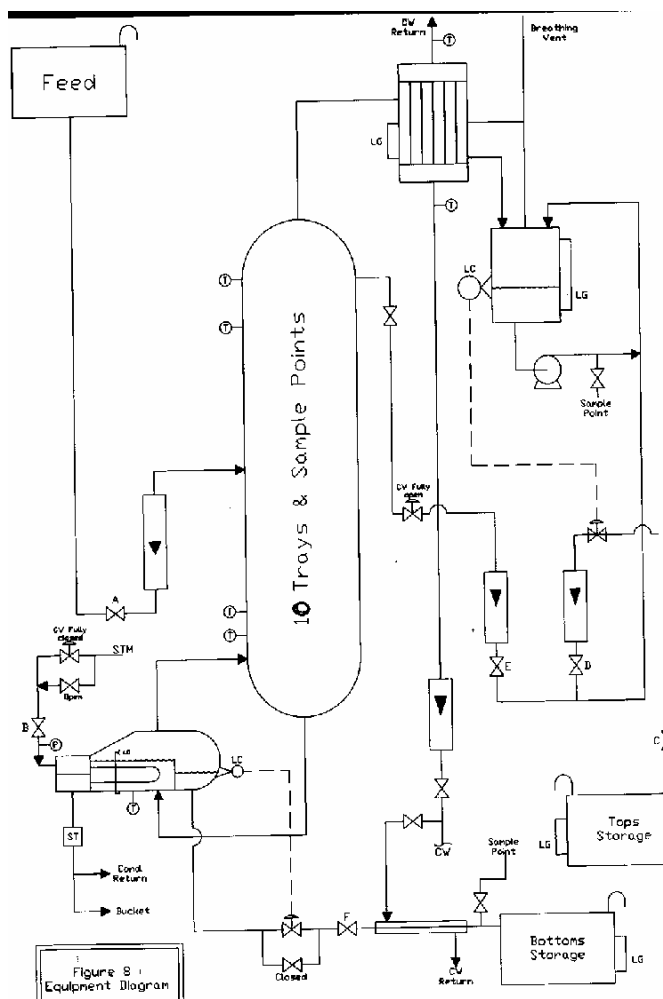
Figure 5.9: Flow diagram of bubble cap distillation column (laboratory manual at the University of Nottingham)

5.3.2 Preliminary

Check the flow sheet and identify all valves, sample points, etc. Sample the feed tanks, and send the samples for analysis by gas liquid chromatography.

5.2.3 Start up and shut down

i) Ensure there is a good flow of cooling water to the condenser and run down cooler.

ii) Start steam flow using valve B, and warm up the unit.

iii) Return all overhead liquid as reflux using gravity flow to start, and then switch on the reflux pump. As the flow increases, limit the flow with valve E once the pump is running.

iv) As the reflux drum reaches a set point, the level control starts to operate.

v) To maintain the level into reboiler, open the feed valve A and the level control valve F.

vi) Steady the steam pressure feed rate and reflux flow using valves B, A, and E. Allow one to one and a half hours to reach steady state.

vii) Collect flow samples and temperature as needed.

viii) To shut down, close valve B (steam), A (feed), and F (boiler level). Turn off the reflux pump after a few minutes and open valve fully, leave cooling water only.

5.3.4 Process description

In practice, distillation may be carried out by either of two principal methods. The first method is based on the production of a vapour by boiling the liquid mixture to be separated and condensing the vapours without allowing any liquid to return to the still. There is then no reflux, which is liquid obtained by condensing the overhead vapours, which are the vapours from the condenser, and returning some of the liquid to the top of the column: this returned liquid is called reflux. The second method is based on the return of part of the condensate under such conditions that the returning liquid is brought into intimate contact with the vapours on their way to the condenser.

In the laboratory bubble cap distillation column, the methanol–water mixture is charged to a reboiler by controlling from feed valve F. Heat is supplied through the coil or through the wall of vessel to bring the liquid to the boiling point and then vaporise part of the batch. The vapour mixture is sent to the column with 10 trays using a pump flow. The vapours are directly taken from the condenser as shown in figure 5.9, and the products are collected in the top

and bottom storage. In the front storage box on the right, at the bottom, the product goes from the top of the column, which is concentrated methanol (e.g., 95%) from the feed methanol (50%), which is stored at the top of the column and fed into the bottom of the column at tray 4. In the rear storage box, at the bottom, the bottom product goes from the column, which has methanol at 20% (i.e., some methanol has been removed from the feed during the process, as it has a higher vapour pressure than the water and goes higher in the column when heated). Two rotameters have been placed to control the volumetric flow of products. Taps are provided on the side of each tray to take samples of the product. A thermocouple is used to check the temperature inside the vessel. Figure 5.9 shows the flow diagram of the process.

5.2.5 Hazard and safety

Name of chemical: methanol

Synonyms: methyl alcohol, methyl hydroxide, wood alcohol, wood sprits, mono hydro methane

Hazard: highly flammable, toxic by inhalation, in contact with skin, and if swallowed

Safety phrases: keep container tightly closed, keep away from source of ignition, no smoking, wear suitable protective clothing and gloves, in case of accident or if you feel unwell, seek medical advice immediately

Personal protective equipment: lab coat, safety glasses, light gloves

Special measure: carbon dioxide extinguisher

Emergency process: turn off steam valve

Physical Conditions: Temperature range up to 165 C

                         Pressure range up to 2 bar g

Chemical involved: steam, water, and methanol

Special precautions: wear personal protective equipment, do not leave the rig unattended during operation, take care when operating the rig, and follow operating procedures regarding maintenance of the rig

5.3 Running the virtual distillation experimental model

It was not possible to fully test the simulation techniques for the virtual learning model. However, it was possible to use the designed model for virtual

learning environments in a training system to discuss its effectiveness for the field of chemical engineering laboratory safety.

Because of the immersive nature of the virtual learning environment, if the learners are placed in chemical plant environments among pumps, heat exchangers, and stand and ladder and pipe work, learners are able to walk around the equipment and practise how to open or close valves and start or shut down the column. Some valves are open or closed in stages, so the user must decide how far to open or close each particular valve. The readings of rotameters and pressure bars placed on the columns are very important for the proper operation of the learning scenario as well as to avoid hazardous situations.

To move around in the three-dimensional environment, curser keys or the mouse can be used. It can be easier for the user to navigate. Also, default hotkeys were defined, which move the user to certain points within the virtual model.

The constructivist virtual model of the laboratory rig has been designed with the following aspects:

(i)   Introduction of the parts of the laboratory rig
(ii) Preliminary check before starting the operation
(iii) Start-up and shut-down process
(iv) Control the process using different valves
(v)   Experiment procedure
(vi) Hazard and safety aspects of operating the rig

There are some certain points inhibiting the learners from entering the laboratory rig straight away. They have some fear of handling equipment and the hazards associated with it. Using such a VLE model, a learner is actively engaged with the learning process.

An idea behind the VLE model is to create constructivist environments in which the learner can understand the basic knowledge of the laboratory rig

with hazard identification and safety awareness. The VLE model will lead to an increase in the safety awareness of the students and an increased familiarisation with the equipment when they perform the real experiment. Some of the process substances (methanol) can reach a concentration high enough to present a serious hazard.

Some of the positive points of the VLE model are discussed here. Figure 5.10(i) is the laboratory rig, while figure 5.10(ii) is the VLE model. First-year chemical engineering students or someone who is entering the laboratory for the first time does not need to know all about the complex structure of the column. Some of the parts of the rig are designed for the third-year chemical engineers, who will be working with the process and improving the column efficiency, or for further development. However, with the VLE model, it is assumed that the simple construction helps the beginners understand the main parts of the rig.

(i) Front view of the laboratory rig   (ii) Perspective view of the VLE model

Figure 5.10

At the beginning of each session, the user needs to decide what personal protective clothing and protective equipment must be worn to navigate safety around the laboratory. Figure 5.11 illustrates that users can choose the safety

boots, overalls, safety glasses, or gloves by clicking on the message box, which can make the learning session safer and more efficient.
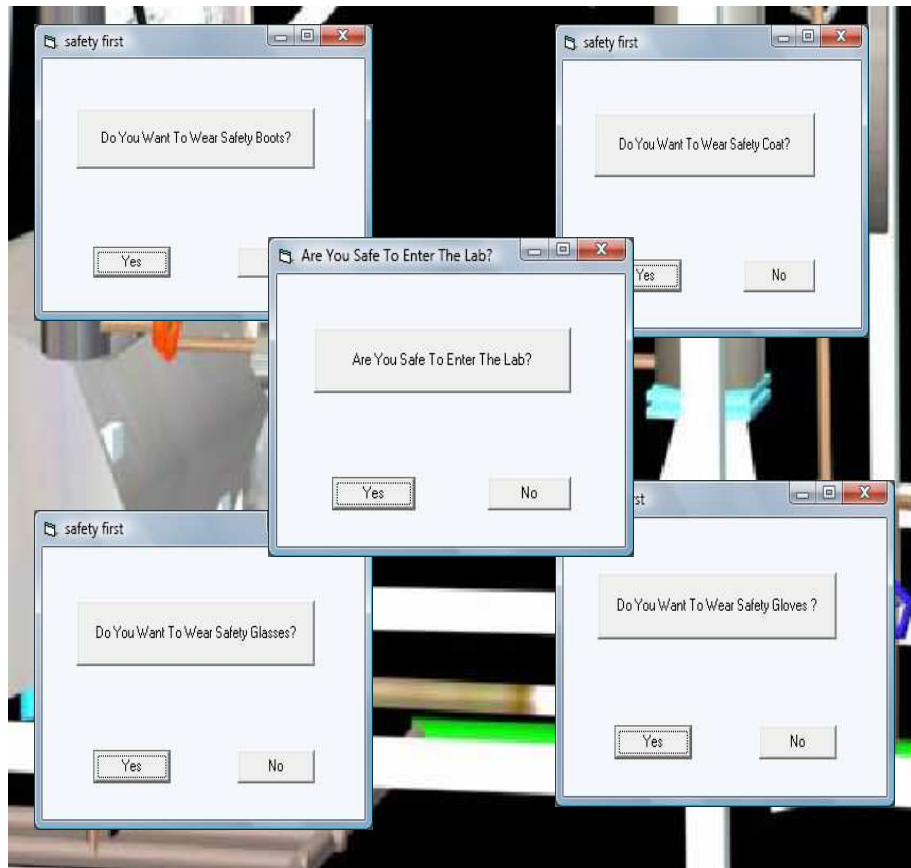
Figure 5.11: Prompts for personal protective equipment

The VLE model will allow the learner to become immersed in the process. First, the learner will set the parameters using the simulated control system. The learner will then enter the value of temperate, pressure, and flow rate of the fluid entering the column. The process will start in the direction shown in figure 5.9. As soon as the liquid reaches its boiling point, an indication is given that the liquid mixture is entering the column by changing the colour of the texture through which it will flow.

Approaching the ladder, which is placed on the left side of the laboratory rig, a message box launches to question the users whether they would like to climb up, as shown in figure 5.12. If their answer is affirmative, the virtual model responds immediately and automatically moves the user up. Users need to climb up to the upper level to check two valves for proper column operation.
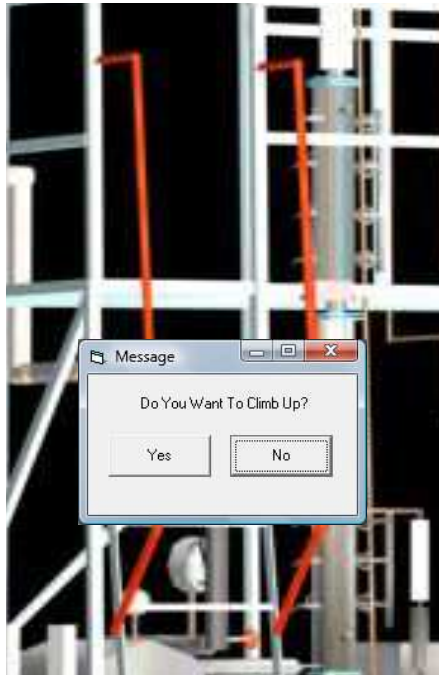
Figure 5.12: Question message box from virtual experiment system

The simulated model translates into a realistic dress rehearsal where the learners can get as much practice as they need. When walking around the model a message box may appear to confirm if you want to measure the process parameter by taking the samples from the taps provided shown in figure 5.13.

Figure 5.13: A reminder message box from the virtual experimental system

Some valves open and close in stages within the virtual world, and some keys have been defined to operate them. In some operations within the virtual model, when a valve comes to its fully open position, a message box appears and informs the user that, for example, 'Feed valve is fully open', as shown in figure 5.14.

Figure 5.14: A warning message box from virtual experimental system

The learners can move around the VLE model concurrently with the simulation, which is running independently. Learners can hear the boiler noise and watch or control valves, pressure or flow meters, pumps, pipe work, filters, heat transfer devices, storage tanks, vessels, and any kind of equipment related to a chemical process.

When walking around to the laboratory rig, learners need to be aware of the associated hazards during the process and with the equipment itself. One of the positive points of the VLE model is that, when approaching any pump, the learners are able to hear the sound of its motor. It is necessary for them to notice that a pump noise is different when a pump hazard is present. Also, users can test their ability to identify leaks from pipelines, barrels, and other vessels that contain toxic or hazardous chemical materials and to check the performance and condition of boilers, pumps, and mechanical equipment, which are located in different places. Being able to navigate around a column

brings many advantages to the design and the control process. As a laboratory experiment, unless learners do not come to any serious problem, they will not be able to handle such a situation in industry or on their own. However, with the VLE model, one can get the control and awareness of the hazard associated with the parameters control. That is, if the temperature is higher than its limit, it will show by changing colour and releasing dangerous alarm sounds.

It was not possible to fully test the simulation techniques for the virtual learning model. However, it was possible to use the virtual learning environment in a training system to evaluate and discuss its effectiveness. Considering the VLE model as a simulated model discussed in this chapter, the research was carried on with two different aspects.

1. Aspects of the simulation model to provide motivation to learners
2. Aspects of the VLE model to develop a range of visual learning presentations for learners.

5.4 Summary

Learners can gain more confidence to perform the real experiment in the laboratory after using the VLE model. They can construct the required knowledge of hazards associated with the laboratory process and parameter control. They will be able to face any problems associated with the process.

With active learning, one can obtain intrinsic rather than extrinsic motivation. One of the limitations of the real experimental rig is that learners could not try to reach the maximum parameters levels and their effects because of the associated hazards. However, the VLE model can provide enough opportunity to immerse the user and construct the knowledge of safety by experiencing failures or accidents with the lack of parameter control or with the lack of safety knowledge.

Chapter Six

Evaluation of Virtual Learning Environment as a Teaching Aid

6.1 Introduction

This chapter details the hypothesis of this research work, which covers the evaluation of the designed column and evaluation of the results.

6.2 Evaluation of designed column

The main aspect tested under this research work was whether beginners learn better from the VLE model when compared with the effect the VLE model has made on the response of experts. The objectives considered while designing this model were as follows: did the VLE model motivate learners, and did the learners find it positive to construct chemical engineering safety knowledge using the VLE model?

The hypothesis was that the response from learners would be positive toward the virtual learning experiment. Chemical engineering subject experts would take the VLE model as a good practice to develop more understanding about safety and hazard awareness. Learners from non-chemical engineering backgrounds would use the VLE model as the gateway for a new subject using the latest technology. Learners would be more enthusiastic about developing an understanding of laboratory hazards and safety awareness. The VLE model should be able to provide the required platform for beginners with its challenging features and easy language used to describe the parts and process. Learners from both groups should find benefit from the simple design of the VLE model. To make the learning process easier, some of the parts
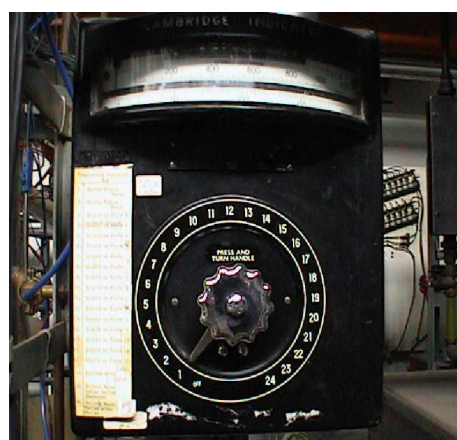
were removed at the time of design. This is discussed later in this chapter. The types of learners taken into consideration while design this model were

 (a) First-time laboratory visitors.
 (b) Students beginning a degree in chemical engineering.

The types of learners mentioned above need motivation and self-confidence to enter the laboratory. The current training given to the first-time visitor is difficult for learners to understand and remember. Sometimes, instruments can be replaced or situations can change, which they tend to remember using photographs. In some cases, this can create more confusion if some of the parts that are not necessary are introduced to primary learners. For example, some of the instruments were designed for the distillation column at the Chemical Engineering Laboratory at the University of Nottingham during the time when latest technologies were not introduced. That part can create confusion to the learner (examples shown figure 6.1). The reboiler in figure 6.1(i) was designed only for research purposes; however, it was removed in the VLE model. Another example is the manual temperature indicator shown in figure 6.1(ii). The purpose of that indicator was to read the process temperature of the column trays. The indicator is out of use because a later temperature control panel has been placed for temperature measurement. The simplest VLE model can provide the learners the required motivation to enter the laboratory rig.

   (i) Laboratory reboiler unit   (ii) Manual temperature indicator

Figure 6.1: The laboratory parts not designed in the virtual experimental model

The photograph in figure 6.3 is the laboratory manual photograph, which is useful in the distillation set up (discussed in the section 5.2 of chapter five). The labelled position of the valves is useful for the students to run the process. Figure 6.3 shows the VLE image for the same laboratory photograph, with very clear positions of the valves.
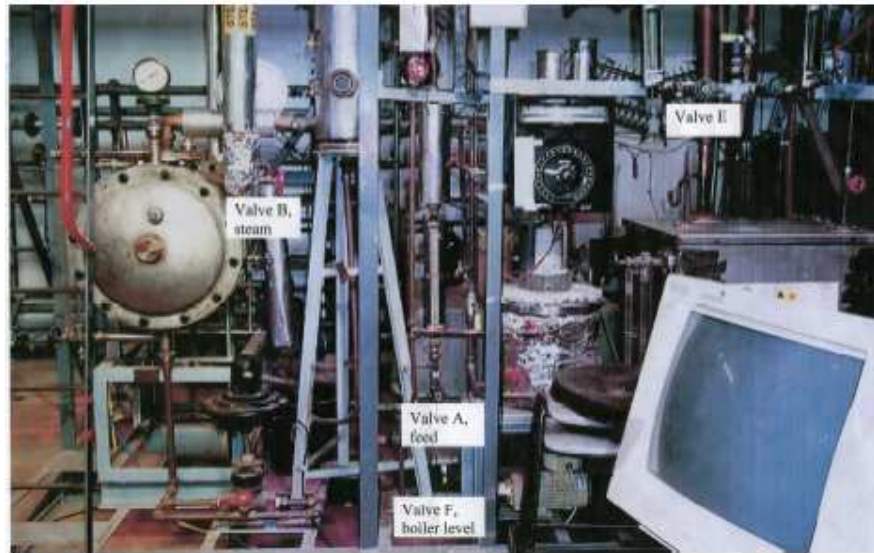
Figure 6.2: Photograph of laboratory set up for the distillation experiment
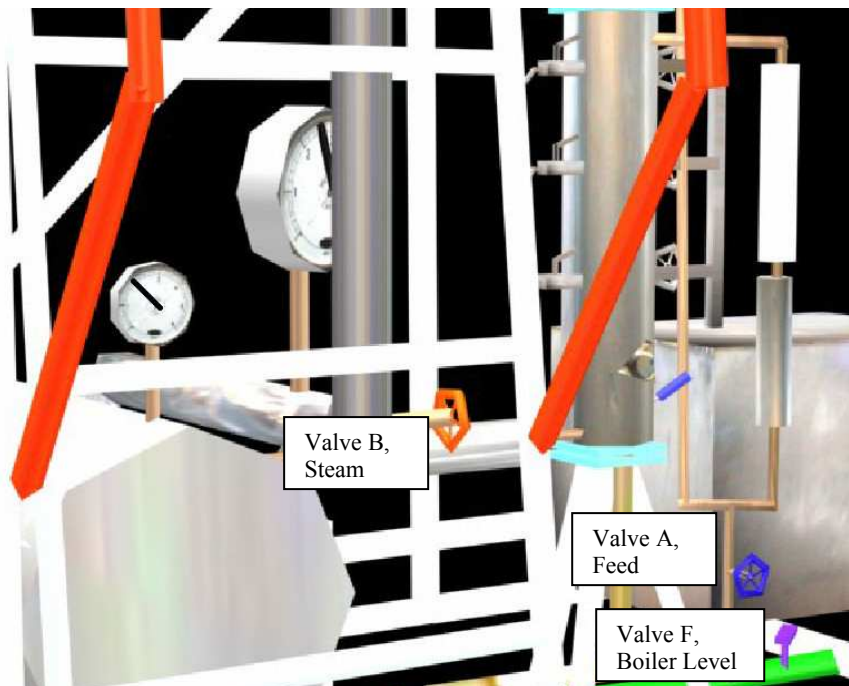
Figure 6.3: Perspective view of the virtual experimental set up

Some of the physical properties may change when the process is working under hazardous conditions. For example, if the temperature is higher than normal, it will show by changing colour using the VLE model shown in figure 6.4.
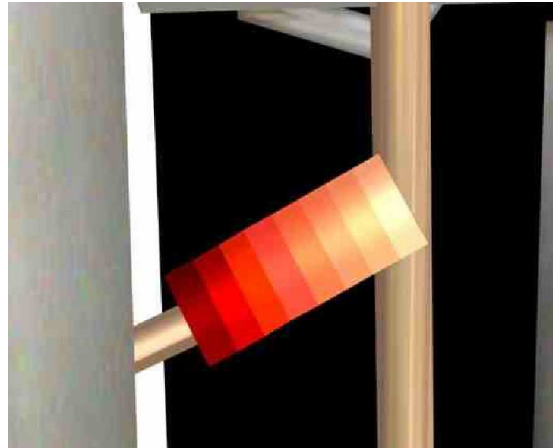
Figure 6.4: perspective view of the thermocouple

To test the VLE model, three different experimental tests were developed using different visualisation techniques in a PowerPoint presentation. The experiments were developed for learners with different background knowledge about chemical engineering. Forty-five learners participated in the experiments
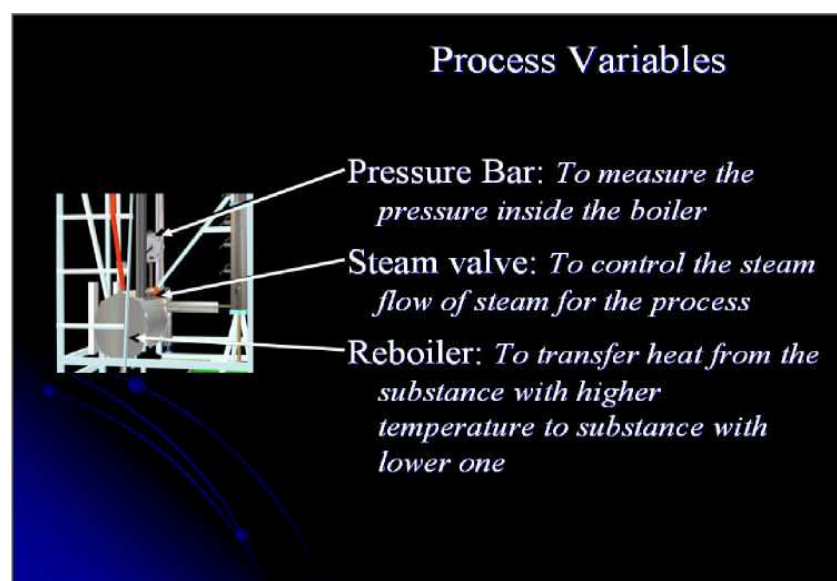
Figure 6.5: An example of a slide of the PowerPoint presentation using the VLE image

Eight slides covered the definitions, identification of the parts, and parameter control. The learners were giving instruction, on a separate sheet, regarding how to use the presentation. Some of them were given personal instruction if they were not familiar with computer tools.
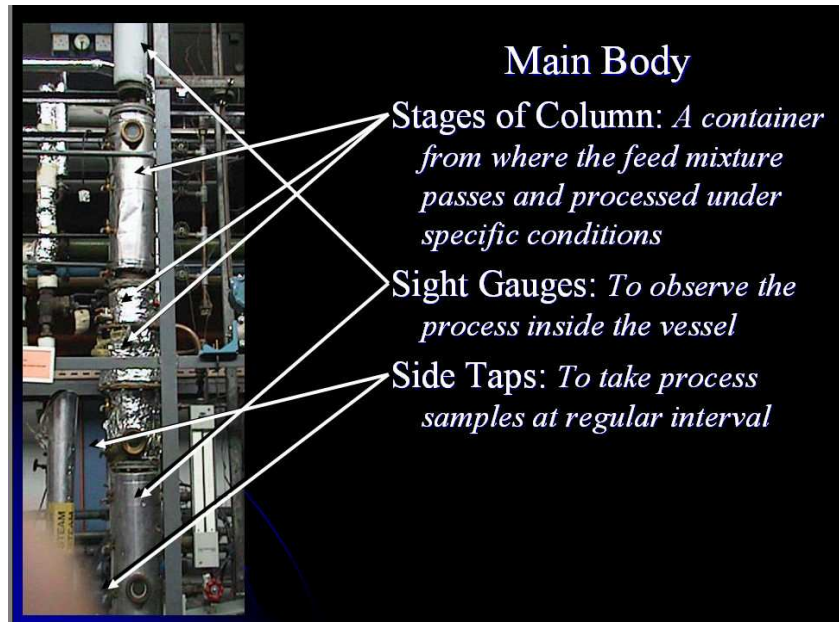
Figure 6.6: An example of a slide of the PowerPoint presentation using a laboratory photograph

An example of the PowerPoint presentation shown in figure 6.5 is one of the presentation slides using a VLE image. Figure 6.6 shows the presentation slide using the laboratory image.

6.3 How the VLE could be used as a teaching aid

The VLE model was designed as a teaching aid for first-year chemical engineering students. Interactive learning modules were designed as a trial for the students at the University of Nottingham. Each of the two different types of learning modules covered the distillation column's component identification, hazard identification, and procedural operations, respectively. The following is a short description of how each module works. The first module was designed using the hazard prescription test concept, which is in use for the driving theory test from the DSA (Driving Standard Agency) for beginners in the United Kingdom.

In one module, learners were allowed to learn using the VLE model without any instruction. As discussed in chapter five, they worked with a number of animation clips to identify hazards associated with the procedure. Learners were required to click on their mouse button as they saw developing hazards. At the end of the animation clips, they were given some score as to how well they did. To improve their mistakes, a short presentation pointed out their errors. The different animation clips covered the following points:

- Introduction of the parts of the laboratory rig
- Preliminary check before starting the operation
- Start-up and shut-down processes
- Process control using different valves
- Experiment procedure
- Hazard and safety aspects of operating the rig

Signs are given showing what learners must not do, and positive instructions demonstrate what learners should do. Warning signs are in triangles. These are for hazard precautions for planning ahead. Some of the signs are for the process control and users see the short animation clips twice. The first time it runs in silence. The animation needs to be watched so the learner can imagine what to do if he or she were running the process. The second time the clip runs, the most relevant hazards are identified, and the most appropriate actions are suggested. Some of the examples of the animation clips are given here.

An animation clip about the preparation for starting up the process includes the personal protective clothing and equipment, which must be worn to navigate safely around the chemical plant. The clip also includes the primary check that all the valves are closed by running the cold water inside the column and checking for any leakage in any pipes. The animation has associated hazards, which learners have to identify by clicking the mouse button anywhere on the screen as soon as they spot the developing hazard. The earlier they identify it, the more they can score. They are given a score at the end of each clip.

Another animation demonstrates hazards associated with the process. This includes the hazards associated when distillation takes place, that is, hazards associated with parameter control (pressure, temperature, or volumetric flow), any machinery failure, or any unusual incidents. The animation has associated hazards, which learners have to identify by clicking the mouse button anywhere on the screen. That is, they click when they notice that the parameter is crossing its normal limit. Again, the earlier identification takes place, the more one can score. The feedback is given at the end of clip.

In the second module, the learner is able to take a virtual tour of the distillation experiment. A single animation will combine the points discussed in the first module. This module will be divided into two separate sections.

In the first section, the animation provides the points mentioned above about associated hazards. Learners have to identify the hazards and find the available safe options. For example, in the animation, the learner may find a person walking without a safety coat on, the temperature above its normal range, or any pipe leaking the process fluid. The second animation runs the ideal process without any associated hazards.

In the second section, the animation provides the combination of both situations in which the distillation process runs in normal conditions as well as when an unusual even happens. For example, in an animation, a learner observes the process close to the column without wearing a safety coat or safety glasses; suddenly, the process runs unusually due to some parameter control, and the learner is injured. The second part of the animation covers the best available solutions to avoid such situations.

It was not possible to fully test these modules on a test group. However, the original simulation was used as the basis of an experiment in which the effectiveness was tested.

6.4 Different visualisation tests

The following three visualisation techniques were used to design the presentation:

- Set I. Use of photographs of laboratory unit: this set was designed using the original photographs of the laboratory column.
- Set II. Use of images of the virtual model: this set of presentation was designed using VLE model images.
- Set III. This set of presentation was designed using VLE animation.

A questionnaire, which is described in Appendix I, was completed at the end of the experiments. The questions were based on visual presentation, which covers the combination of both visualisation techniques. Learners answered questions not only from the visualisation technique they used, but they also answered the questions using other visualisation methods. It was assumed that learners that performed with set II and set III should find the questionnaire easier to answer rather than learners who used set I. Because of the use of real photographs, it could be hard to remember the place of any valve or indicator with its very complex structure. However, with set II and set III, the simple design of the construction made it easier to remember these points.

6.5 Evaluations of results

Several variables were considered for all learners as background data and to determine their impact on the learners' performances. Subjects were divided into two groups. Group A was the learners from a chemical engineering background, and group B was the learners from a non-chemical-engineering background. The number of subjects was highest in the age group 16–25, as shown in figure 6.6
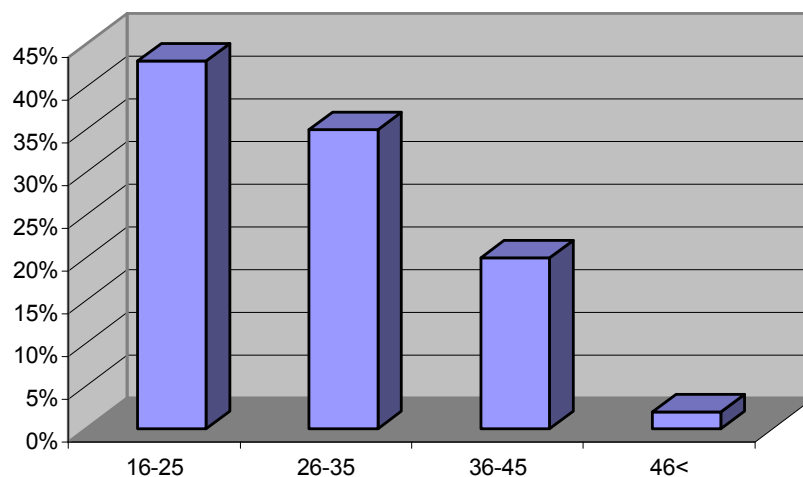
Figure 6.6: Age of subjects

Results show that subjects of group A scored highest using set I while group B scored well with set III. Therefore, the overall result was not strong enough to favour any particular set of experiments, as indicated by the graph in figure 6.7.

Subjects were asked if they believed the virtual learning environment could help students understand the real experiment. Almost all subjects from group B answered affirmatively, and they made very positive comments about the educational use of the virtual distillation experiment. They suggested that this was a valuable and useful tool for enhancing the learning of chemical process fundamentals. The graph presented in figure 6.8 indicates the positive comments of subjects from group B and a mixed reaction from group A.
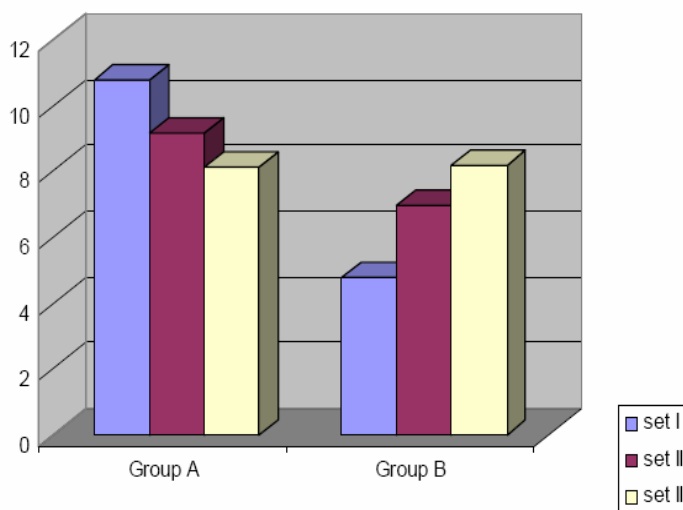
Figure 6.7: Average score of subjects

Subjects were asked whether they felt they were visiting the place rather than simply seeing images. The majority of subjects from group B showed a positive attitude toward the idea that the virtual learning environment could make one feel as if he or she were visiting the laboratory rather than just seeing images. This is shown in the graph of figure 6.9, which also shows the neutral response from group A.

Do you think that it would help students to understand the real experiments?
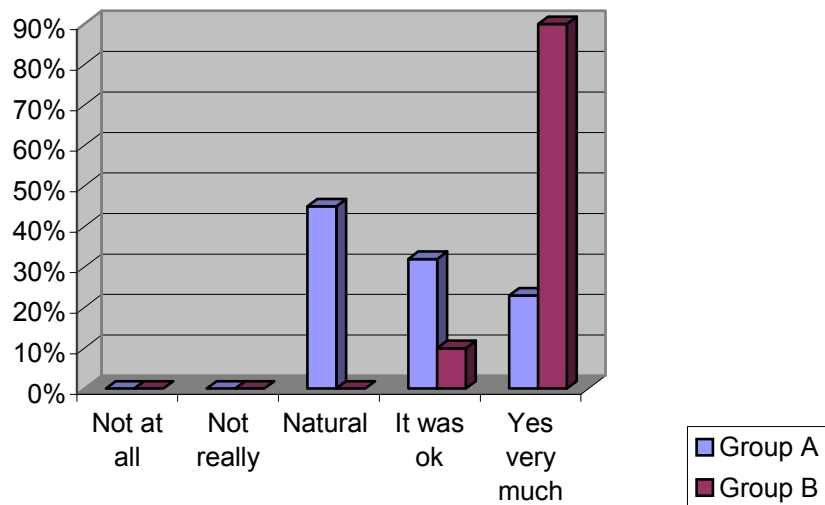
Figure 6.8: Would the virtual environment help learners understand the real experiment?

Did you feel as you were visiting the place rather than simple seeing images?
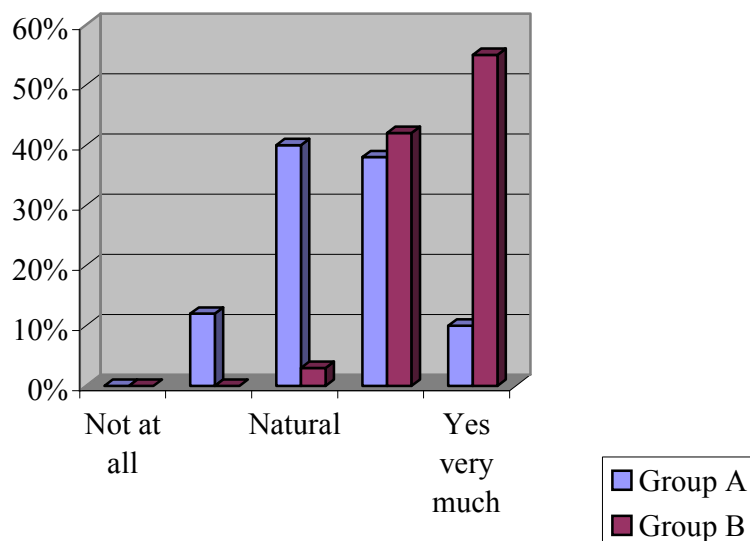
Figure 6.9: Comparison of the virtual world with pictures from real rig

Subjects were asked the questions to indicate the level of motivation they felt when dealing with visual material contained in the learning model. Again, extreme answers were expressed from the subjects from group B. They indicated that they considered the virtual learning environment to be a realistic representation, as shown by figure 6.10. Subjects felt like they were visiting the place rather than simply seeing images, so the views were positive. Group B, who performed set III, was more enthusiastic. They found it more of an exciting, game-like technology in which they can take a challenge, and the animation was found more interesting than looking at photos and reading definitions in constructing knowledge. The VLE model did not influence subjects from group A. They expressed a mixed response by indicating that the VLE model can be OK or normal for learning the concepts. None of the feedback was negative.

Does it motivate for performing real laboratory experiments?
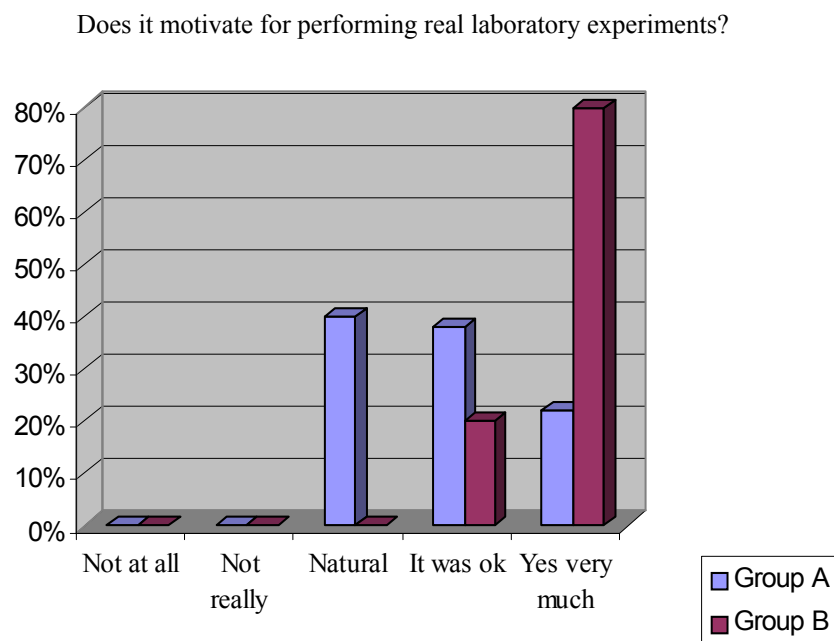
Figure 6.10: Would the virtual environment be motivating to learners?

In the last question, the subjects were asked whether the virtual learning environment was able to create constructivism for the laboratory procedure and the process of distillation. The majority of subjects from group B showed a highest enthusiasm towards the VLE model. They indicated that the VLE model could be helpful for promoting constructivism. Subjects from group A have indicated that they are not constructing knowledge using these sets of

experiments. They are using their existing knowledge to answer the questions.

The hypothesis given at the beginning of this chapter—that the VLE model would promote constructivist learning—is therefore confirmed for the beginners group. However, as the experts had little knowledge to construct, they predictably showed only a neutral response.

Did you feel the virtual learning environment could be helpful for constructivism?
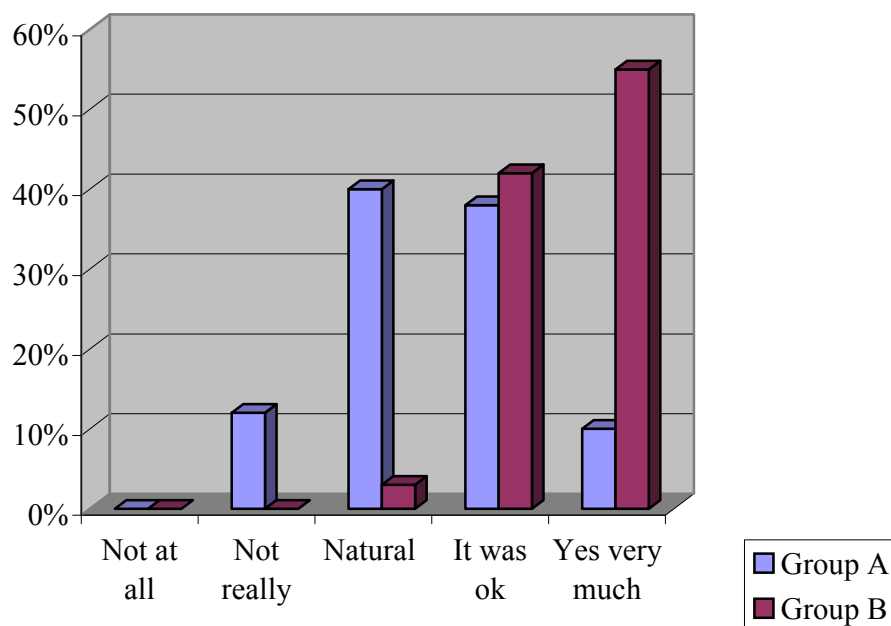
Figure 6.11: Use of the virtual learning environment for constructivism

The points mentioned by the beginners for the virtual experiments are listed here:

- Simple definitions, process description, and procedural aspects were made easy.
- The design was made simple and easy to understand using computer techniques.
- Questions were asked in consideration of beginners and by providing a mixture of the different sets of visual presentations images.

6.4 Summary

As a chemical engineering expert myself, the analysis shows that the experts who are already dealing with or have come across the distillation process before already have awareness of laboratory safety and hazards. This group of learners already has some images and existing knowledge of laboratory processes and safety awareness. They found it easier to work with real photographs rather than using the VLE model. They were not constructing new knowledge using the VLE model. However, they were using their existing knowledge to deal with the questionnaire. Another reason for their response could be because the VLE model was simple in design, as it had to maintain lower numbers of polygons, and some of the parts lost their original smoothness and shape. For this reason, the VLE model was less likely to provide constructivist learning for group A, which was indicated by the mixture of results achieved from group A.

The hypothesis that the VLE model would promote constructivist learning was reinforced. Learners from group B (the beginners) performed significantly better when trained using the VLE than when trained from the PowerPoint presentation in which only static images (whether ideal or from the VLE) were presented.

Chapter Seven

Summary and Conclusion

7.1 Introduction

This research set out to investigate aspects of the application of the virtual learning environment to promote constructivism for chemical engineering and especially safety awareness. In this chapter, a brief overview of the thesis is given, followed by a number of conclusions and recommendations, based on the research, regarding the suitability and future applications of constructivism and the virtual learning environment in chemical engineering education.

The aim of the research was to establish whether a constructivist virtual learning environment led to better understanding of chemical engineering laboratory safety and hazard awareness when compared with classroom learning.

As a result, the major objective of this research was to develop the virtual learning environment and to examine the suitability of the virtual learning environment for chemical laboratory safety and hazard awareness.

7.2 Overview

A chemical reaction that goes out of control can create a serious accident with the risk of injury to people and damage to property and the environment. Such accidents result from one or other types of errors associated with the process. Safety aspects must be taken into account during the training of employees to operate chemical engineering equipment.

Traditional teaching methods have difficulties in teaching students the laboratory process and procedure without entering a laboratory. It is also extremely difficult for traditional teaching methods to simulate processes in

the chemical engineering field or to give the opportunity for learners to practice and test their abilities and their knowledge. Traditional methods of teaching do not allow students to experiment with the different types of equipment involved in the chemical process.

Virtual reality was identified as the computer-based technology that is already used for a variety of applications. The development of computer hardware technology has improved the quality of virtual reality systems and has reduced the costs associated with such systems. Virtual learning environments can be used for further understanding of a concept and making the concept more concrete and real to the learner. Virtual learning environments allow the student to control the learning process (Nasios, 2002).

The ability of virtual learning environments to simulate complex chemical engineering processes in real time allows a trainee to have experience of an environment that changes over time. Using a virtual learning mode of real equipment is risk free and allows endless experimentation. Allowing users to learn within computer-generated environments provides the opportunity for them to make mistakes and suffer the consequences without putting themselves at risk. Virtual learning environments can allow learners to experience unusual or potentially dangerous occurrences from a position of safety. Chemical engineering laboratories can be dangerous, whereas virtual learning environments have a great potential for application in safety and hazard awareness. The virtual learning model can motivate learners by the ''immersive'' nature of its design. Learners can take it as active learning by its challenging and immersive features.

7.3 A virtual learning environment for the bubble cap distillation
This virtual environment was based on an undergraduate laboratory experiment for the chemical engineering degree course at the University of Nottingham, focusing primarily on learning and safety issues of laboratory visitors. The virtual distillation experiment not only familiarises students with the fundamental features of the distillation column experimental apparatus, but also teaches the procedural and safety aspects of the process.

The operation of chemical engineering instruments and the knowledge gained by using this virtual laboratory rig layout will help learners know exactly what tasks they should follow and what precautions they should take before they implement the experiment in the real laboratory. Learners are able to set experimental tasks in the virtual world, and if they make any mistakes, they will learn what went wrong without damaging equipment or themselves.

7.4 Use of the virtual learning experiment as a teaching aid

The virtual bubble cap distillation experiment was considered an ideal teaching method that can help learners to implement and understand 'real' experimental procedures. It is never suggested that the virtual world should be the replacement of the real laboratory experiment. However, it can be considered as a developmental teaching aid. The learners can be actively involved by their actions while having control over the parameters. This can increase the users' capacity for critical thought and encourage them to take a 'deep' approach to learning. However, virtual learning environments should be used as a supplement to real experience, and in situations in which the real experience is not possible due to safety reasons.

To complete the objective, a virtual learning environment was created using 3D Studio Max software based on an undergraduate laboratory experiment for the chemical engineering degree course at the University of Nottingham. The VLE model of the distillation experiment focused primarily on training and safety issues for students performing the experiment. The virtual learning environment was created principally for first-year chemical engineering students and first-time chemical engineering laboratory visitors. These types of learners have some fears in dealing with chemical engineering from a subject point of view and from the point of safety and hazard. It was not possible to fully test the simulation techniques for the virtual learning model. However, it was possible to use the virtual learning environments in a training system and to discuss their effectiveness for the field of chemical engineering laboratory safety.

Different visual presentations were produced to demonstrate the potential of the virtual learning environment to promote constructivism in the field of chemical engineering. The visual presentations were developed using the following visual techniques:

- Set I: developed using the photographs of the laboratory rig
- Set II: developed using the images of the VLE model
- Set III: developed using animation of the VLE model

Two different groups were selected for the evaluation trials of VLE model, including learners from a chemical engineering background and learners from a non-chemical-engineering background. At the end of the presentation, learners were asked to answer questions, which covered a combination of the previously mentioned three sets of visual presentation. They were also requested to give their feedback about the use of the virtual learning environment in promoting constructivism.

7.5 Evaluation of results

The evaluation of the use of the virtual bubble cap distillation experiment produced balanced feedback representing the suitability and effectiveness of the virtual learning technology and concepts. The group of learners from non-chemical-engineering backgrounds provided positive comments regarding the usefulness of the virtual learning environments as teaching aids. The group of learners from non-chemical-engineering backgrounds also enjoyed the interactive nature of the virtual learning environment, with its visuals and sounds effects on process safety and hazard awareness. The group of learners from a chemical engineering background produced neutral indications toward the virtual experiment's suitability as an effective means for teaching and learning.

As discussed in chapter six, the result analysis shows that the experts who are already dealing with or who had come across the distillation process before have awareness of laboratory safety and hazards. This group of learners already images and existing knowledge of laboratory process and safety

awareness. They found it easier to work with real photographs rather than using VLE model. The reason was that because there had been an attempt to make the VLE mode easier in design to maintain lower numbers of polygons, and some of the parts lost their original smoothness and shape. For this reason, the influence of the VLE model was negative in constructivist learning for the learners from chemical engineering background. In fact, they did not learn any new concepts; they used the exciting knowledge, which was indicated by the mixture of results achieved and discussed in chapter six.

The virtual distillation column model provided the user with a better understanding of the layout, the size, and the movement of the objects within the environment. Three-dimensional visualisation provides a good alternative in situations in which it is impossible to gain first-hand experience of an environment. The application of the virtual distillation experiment allows the rig and the chemical process equipment to be viewed from any position and angle, including many which are not possible in a real laboratory.

Within this research, the work was to design the bubble cap distillation column using 3D Studio Max. This model was selected for the part of the visual learning presentation, which was developed using three visual techniques as discussed earlier in this chapter. However, it was assumed that the VLE model could work as one walks through and can process with the model as discussed in chapter five, section 5.3. It could be more interesting if the VLE model were used for a game learning in which the learners could benefit from the game learning aspects, that is, setting a goal, learning as a challenge, learning with self-confidence, or improving learning using feedback as discussed in section 6.3.

7.6 Summary

Virtual learning environments have the potential to teach or to promote constructivism in the field of chemical laboratory safety without any associated risks.

Virtual experiments will undoubtedly widen the variety of teaching media used in the chemical engineering course and will introduce new teaching methods for implementing and understanding 'real' experimental laboratory aspects.

The designed modules can provide the learning platform for the chemical engineering students. Students have more enthusiasm for the playing and scoring nature of the modules. Such modules can provide motivation to beginners as a means of making them safe in using the equipment and in being aware of safety and hazards.

7.8 Recommendations

The following are some recommendations that have arisen from the research work:

- Virtual learning environments should be introduced to the chemical engineering industry to enhance current training programs.
- Games learning should be introduced in chemical engineering laboratories to help students develop a deep and reflective understanding of the subject and to help them develop capabilities, skills, and experiences essential for further study and future employment.
- Mobile learning should be encouraged for further research in the field of chemical engineering laboratory safety, which can lead to the use of mobile learning in the chemical plant industries.
- Introducing the designed modules should encourage the development of virtual learning environments for educational chemical engineering laboratories.

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