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Development and Deployment of a Library of Industrially Focused Advanced Immersive VR Learning Environments

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ABSTRACT

This work presents a unique education resource for both process engineering students and the industry workforce. The learning environment is based around spherical imagery of real operating plants coupled with interactive embedded activities and content. This Virtual Reality (VR) learning tool has been developed by applying aspects of relevant educational theory and proven instructive teaching approaches. Principles such as constructivism, interactivity, cognitive load and

learner-centred design have been central considerations when constructing and structuring this resource. Structural challenges include determining a framework for the basic environment, the repository for the VR and activities, as well as the development of a learning platform arrangement to support self-directed learning in the interface. The system's current functionality is demonstrated through video imagery of a user performing activities as well as snapshots of the current screen configuration. Current feedback regarding the interface is acknowledged and future work responds to the key issues presented by these studies.

Keywords: virtual reality, immersive learning environment, process engineering

OVERVIEW

Opportunities for providing visual context for process theory in real operating systems are increasingly less accessible to students. Costs, litigation concerns as well as logistic constraints make both plant operators and university staff hesitant to conduct large scale plant tours. Additionally, the

Figure 1. Virtual Process Plant Launch Page.

demise of most industry cadetships in Australia, means students have forfeited the opportunity to see engineering in practice. This therefore leaves a significant gap in the conceptual understanding of the current process engineering undergraduate [1].

Within industry, there is a need to establish training packages which deliver a consistent message to operations and engineering staff. With round the clock operations in most process plants, there is also a desire to provide a learning platform which is accessible and available 24 hours a day. Obviously a learning structure which reduces the requirement for trainer supervision, without diluting the key learning outcomes, provides industry with undeniable cost and training benefits.

This work directly addresses these parallel needs of university and industry. For university students, the real plant is brought to the learner, through a set of virtual reality (VR) immersive environments. These environments enhance insight and understanding by providing:

- A real engineering context within the different plants
- Relevant activities and information pieces embedded within the VR imagery
- An exploratory platform to discover and investigate at the individual's own pace [1].

Benefits are equally available to our industry partners. Company staff can utilize the environments to:

- Showcase their industry to the general public
- Provide the basis for general site inductions
- Conduct operator training on specific equipment
- Shed light on the pieces of process equipment generally regarded as "black boxes" by process operators.

Through application of this learning tool, industry is given the opportunity to provide a level of consistency in their operator training, through an easily accessible platform, which does not require intense supervision or support.

The application of VR technology in this setting supports visualization of systems in a sphere which is not intrusive on the operational plant but offers experiential learning opportunities without risk of serious consequences. With its modified view of reality, users are allowed to explore beyond traditional boundaries into pieces of equipment and their operation. Immersion in the VR leads to a sense of "being there" which is associated with genuine psychological learning benefits. Within this setting, users are able to direct their own learning in a style espoused in constructivist philosophies and by learner-centred practices. The visual strengths offered by VR are strongly aligned with the learning preferences of the users and support easy translation of the dynamic content into imagery suitable to the audience.

Figure 1 illustrates the launch page for a prototype VR system that commenced development at The University of Queensland during 2005 [1]. The development of this VR immersive environment

prototype system and the on-going associated activities has been supported by BP (Bulwer Island) Refinery, Brisbane, Australia. Within the prototype environment tours, both guided and self-guided, and various activities and animations including a distillation animation and a pump isolation activity have already been embedded. It is planned to include more activities in this environment. Some activities that have been formulated for inclusion in this refinery-based environment include a wonder-why tour exploring the design basis for equipment used in the plant and a mass and energy balance activity which is introduced as a problem solving task framed around product quality issue.

Development of a second immersive environment covering Coogee Energy's compact methanol plant based in Victoria, has commenced. Showcases of the prototypic environment to other industry groups has generated interest from Alcoa (WA), BHP Biliton (Vic), VISY (NSW), Qenos (NSW) and Veolia Water Australia (NSW) and may result in the addition of more industrial applications to the interface to create a library of VR immersive environments.

Development and base-level structuring of the prototype VR system has considered transferability to other process industries. A base-level menu structure housed within the VR has been selected. This best utilises the strengths of the immersive environment and provides an intuitive means of accessing activities and information embedded within the environment. This supports the generation of a VR immersive environment library of process engineering applications.

The exact framework of the library of VR environments and its interface is still to be determined. In application of this framework we hope to:

1. Create an interface which supports self-directed learning; hence it has a web of learning paths through which concepts and conceptual difficulty build.
2. Frame information and activities in a system that is engaging and entertaining so learning is enhanced.
3. Apply an interface that can be used within an internet browser platform.
4. Use terminology and course language that is not university or site specific.
5. Support a simple means of assessing the success of the learning tool against its stated learning outcomes.
6. Develop a platform that has a low dependency on both hardware and software.

Some of the options being considered for the library interface include:

- A game based environment—where successful completion of a task gives a user further power to acquire knowledge. There is an established set of pre-requisite skills required before embarking on certain tasks.
- A problem-based environment based on a day in the life of an engineer—users are confronted with an issue with plant operation or a daily operating constraint that they are asked to resolve or provide an alternate operating strategy to combat.

- A knowledge bank where users can deposit "tools" of the trade. In performing each task, users are asked to bank the concepts or "tools" that they have discovered, applied or appreciated during the activity. Within the bank, the tools are structured and linked within a concept maps generated by the user.

Defining and developing the structure of the library interface as well as establishing a framework to assess the underlying educational benefits of utilising this interface form the next challenges.

BACKGROUND

Educational technology is a field of study aimed at determining how best to use multimedia as a teaching resource [2]. Unfortunately, this field of research is developing at a rate significantly slower than technological capability. As a result, the design and development of educational resources are often driven by technological potential rather than validated educational theory. In an attempt to circumvent this complication, we have attempted to base the design and development decisions on educational theory and proven practices. The following section gives a brief overview of the relevant theory and its application in e-learning environments.

Educational Theory

Learning is driven by a genuine developmental need created by a disturbance, breakdown, problem or by questioning status quo [3]. Constructive or generative learning is a process in which learners build a framework networking their knowledge. Meaningful learning takes place when learners select and structure their own learning and integrate it with their current knowledge [4]. Usually this involves students mentally animating a process and then connecting visual and verbal mental models [5].

Learning is said to be limited by processing power. This gives rise to a gamut of educational theory related to cognitive load. Ploetzner and Lowe [6] believe that individuals possess a maximum processing capacity which limits the transmission of information through learning channels. Exceeding maximum processing power results in cognitive overloading which in turn can lead to under-processing of information [4].

When teaching methods consider cognitive load, the management strategy involves reducing extraneous load (mental effort required to manage how information is presented) and increasing germane load (mental energies directed towards learning, structure and embedding knowledge) while acknowledging the diversity of student's intrinsic cognitive load (mental capacity and pre-knowledge) [7].

Dual code theory was discussed by Mayer and Moreno [4]. They enhanced the concept of cognitive load by theorising that there are different processing systems for verbal and visual materials. Each coding channel has limited cognitive load capacity but they operate independently of each other. When processing information, two mental models are formed simultaneously, one on the basis of the aural channel and the second through the visual channel. These aural and visual models are integrated with prior knowledge to generate conceptual understanding.

When dual code theory was overlaid on cognitive load theory, it gave rise to a number of principles which form the basis of instructional design in educational multimedia. These are best documented by Mayer and Moreno [4], [8] and [9] , although tested and proven by a number of other authors [10–13]. These principles include directions on methods of presentation of educational material to best ensure the concepts are embedded. Examples include the Multiple Representation Principle which dictates that explanations in words and pictures are better than words or pictures alone and the Modality Principle which indicates that auditory narration alone is better than on-screen text accompanied by narration.

Schwan and Riempp [13] investigate the benefits of interactive over non-interactive educational multimedia. By interactivity, they include means such as pause, play and repeat functionality in their software. This interactivity supports the adaptation of the educational medium to learner's needs. In terms of cognitive load, interactivity diffuses the diversity of student's intrinsic cognitive load, by allowing users to set the pace and sequence of a presentation according to their own skill level and cognitive capacity.

Educational Approaches

Whereas traditional teaching philosophies were based on an objectivist model being essentially a knowledge telling strategy, new approaches espouse a constructivist approach, a knowledge building strategy. In contrast to the objectivist model, the student directs their own learning and the teacher becomes the motivator, supporter and guider. The model means education needs to help students collect tools to become better self-directed learners rather than teach facts and figures [14].

Cognitive tools are often utilised to help students perform tasks that may be considered out of reach or beyond their abilities. This extension of abilities is scaffolding [15]. These tools also assist by supporting cognitive processing, sharing cognitive load or allowing users to visualise, analyse, interpret, rationalise and develop information [16].

The user interface employed is the real determinant of a e-learning tool's success. A system which is complex, un-interesting and poorly constructed will be discarded quickly, irrespective

of the learning opportunities it holds. The interface design must take into account the needs, experience and capability of the user. Potential users should be involved in the design process and prototyping is essential to ensure their feedback can be incorporated [2].

Human-Computer Interface (HCI) [2, 14, 17] design becomes important. HCIs are developed based on the needs of the human using them rather than the systems or tasks they replicate in the hope of replacing a user. The user is central to the design and the software is developed to simplify user tasks, support and streamline work-processes. Typical user-centred approaches consider the user as the designer and encourage prototyping and user-testing. Usability studies evaluate the appropriateness of the techniques used to mediate technology to support the user [18].

User-centred practices are not as easily facilitated when designing educational material since they are complicated by the fact that as the end-users of the teaching interfaces, the students, are user-novices and not experienced enough to make significant design decisions. As a result, Blythe [19] encourages educational designers to adopt a user-centred attitude to instructional design rather than explicitly follow user-centred design principles.

The learner should be an active participant in the process of creating educational software; however their involvement may be better utilised in reviewing prototypes rather than establishing design specifications. To combat this lack of learner-involvement in the design phase of software creation, extensive user-profiling must be performed prior to development of prototypes [20].

Technology employed in learner-centred instruction should complement the user and not intrude upon the work of the human in the interface. Not only should technology be invisible to the user, it should compensate for deficiencies in expertise and therefore reduce extraneous cognitive load while providing cognitive relief [5]. Technological aids should replace general and regularly applied rule-based routines and behaviours [21], giving students space to explore the environment and direct their own learning.

Learner-centred instructional approaches show a strong alignment with constructivist philosophies. Learner centred design involves scaffolding to address the unique needs of the user [22]. With the student central to the design, the learning premise is based on self-directed exploratory research of the interface. Since self-directed learning is more personally meaningful, it is hoped that the teachings are more likely to be embedded. When focussing the interface on the user and allowing them to direct their own path through the medium, it is possible to negate the difficulties created by designing for a diverse group of users. Other functionality which supports the user-centric philosophy is providing the ability to customise the interface to suit the student [23].

Learning Platforms

Three learning approaches considered in more detail for this work, which encapsulate key aspects of educational theory and the principles of constructivist e-learning environments include:

1. Concept Mapping
2. Educational Games
3. Problem Based Learning

Concept Mapping: Ellis et al. [24] articulates the difficulties facing engineering educators. They indicate that the focus of a number of engineering courses is to teach how to solve a set of problems. Unfortunately, the transferability of these lessons is not evident and students are not able to recognise the problem, categorise an appropriate solution procedure and successfully apply the procedure to the problem unless the problem is identical to that taught or practiced. Engineering educators are therefore looking for innovative ways to frame lessons to ensure that meaningful learning takes place. One such strategy encourages engineering students to see the big picture. This is the practice of concept mapping.

Concept mapping involves internalising the learning, interpreting and understanding how the concept interacts with the other pieces of existing knowledge and then outputting this knowledge framework explicitly in the form of a map. This requires a deep understanding of the concept and how it fits into their education. Educators can assess whether meaningful learning has taken place, by simply reviewing the concept map produced.

Concept maps are student-centred learning tools as they present the student's view of their current knowledge network. The process of creating a concept map involves organising information into an internally coherent framework and hence, according to Gros [2], is, by definition, a constructivist task. Sedig et al. [16] concurs, indicating that the process of verbalising cognitive maps is true constructivism in practice.

Educational Games: The computer game or competitive theory has been applied within learning platforms to enhance educational understanding in a number of medical, information technology (IT), military and early educational fields. CyberIST [25] employed a game philosophy to develop a medical education package. This was a simple game set-up where students were presented with questions and they were required to answer them within specific timeframes. To encourage the competitive spirit, a leader-board tallied the results. The strengths of this learning program were accessibility, creating a competitive drive to succeed and the informal learning opportunities offered by conversations between students. Quest Atlantis (QA), an educational game for younger students, succeeded in making learning fun. Its learning platform combines strategies used in commercial gaming with those of educational research into motivation and knowledge acquisition [26]. The strength this combination offers is an experientially based learning opportunity with active participant

involvement at an emotional level. It employs 3D immersive, multi-user environments, educational quests, comic books, a novel, a board game, trading cards, various characters and certain social commitments to deliver the educational messages subliminally [26].

Barab et al. [26] discuss the key elements of any educational game platform. In their list they include:

- A mythological content. Fantasy is a strong motivating element but must be carefully chosen to appeal to the target audience. If students are permitted to adopt a different persona it can give them anonymity and possibly invigorate their confidence to perform to or beyond their potential.
- Spaces where interaction can take place both with other game players and with the characters or pedagogical agents established in the game.
- A well-defined advancement system based on pedagogically valid educational activities.
- Regalia and rewards which provide performance feedback as well as having motivational effects.
- A home page per student which can act as a repository for work and a record of their progress

Problem Based Learning: Problem based learning (PBL) is based on the theory that learning occurs in the process of solving a complex problem [2]. Provided the complexities are authentic, the strength offered by this form of learning is the likeness of the problem setting to that facing a student in the real world. Cognitive tools help build a knowledge construction environment [15]. Generally through the application of PBL, there is a shift in the roles of the teacher and the student. The student becomes the inquiring, active seeker of knowledge and the teacher the sideline supporter and guide [27]. The teaching challenge then becomes one of provision and timing of support rather than presentation of content. This role-reversal suits the e-learning arrangement offered within a technologically based application such as an immersive environment; however it does have its shortcomings. The success of PBL is undeniably linked to the level of active participation and self-directed learning drive the student possesses. To encourage participation, the learning environment has to offer a captivating platform, a strong basis for constructive learning and plentiful opportunities to seek assistance and collaborate. These needs are easily catered for in a hypermedia based, computer environment.

Users

A common fault with computer based learning environments is that they fail to cater for the diversity of their users. It is not easy to anticipate or suit different levels of processing ability, learning mode preferences and different methods of use simultaneously [10, 17]. This leads most designers towards a user-centric approach. In user-centred systems, the user is directing their

own passage through the medium, at their own pace and using tools that are suited to their needs and preferences.

In the development of educational multimedia, the principles of user-centred design are difficult to apply because the end users of the resource, the students, are not experts in the subject matter. When designing computer based learning programs for students, to combat this issue, there must be considerable learner profiling performed.

Target Audience: A potential stumbling block for this project is the breadth of the application's target audience. This learning tool has been designed to assist two significantly different target groups: operations personnel and undergraduate process engineering students. The operations personnel differ from site to site and so does the profile of the undergraduate process engineering students as you move from university to university around Australia.

Our primary target audience is undergraduate process engineering students, initially, in Australian universities. The application can be used by first year students through to final year students. Undergraduate students have a strong theoretical background but often lack an appreciation of scale and operation.

Process operators are the exact opposite. They have a genuine knowledge of operation and its response to change but they lack a deeper understanding of the theory or rationale behind the process effects.

Visualisations and animations are appropriate in engineering education, primarily because the content possesses dynamic concepts [28]. This suits both target groups, who show a strong preference for spatial and visual imaging in their learning styles.

Learner Profile: Characteristics of the learner that are deemed to have an affect on their learning preferences include: Age (years of experience), gender, level of education, affect or mood and motivation [29]. A summary of our two target groups in terms of these characteristics is included in Table 1.

Characteristic	Undergraduate Process Engineering Students	Process Operators
Age (Years of Experience)	18-22 years (no work experience, strong computer skills base)	25-65 years (5-30 yrs work experience, weak computer skills base)
Gender	40% female, 60% male	5% female, 95% male
Level of Education	Tertiary level	Secondary School Level
Affect or Mood	Variable	Controlled
Motivation	Assessment driven	Financial, Self-improvement

Table 1. Learner profiles.

Prior computer experience has been identified as a key antecedent to the success of a computer related task [30]. Generally the older the person, the less experience they have with computers.

Females have a preference for word processing and collaborative work on computers whereas males like competitive learning as found in educational games. It has been found that women approach computers with less confidence and more anxiety than men [29].

Rozell and Gardner III [30] showed that a learner's mood will affect their level of effort expended. By providing unexpected gifts to learners, their ability to solve problems improved. This shows that mood can be manipulated to place learners in a more productive state. The provision of gifts should consider the variety of motivations.

Virtual Reality

A virtual environment is a modified user environment which provides an altered context in which to work or play [20]. It provides opportunities for users to have an immersive experience in ways not possible in the real physical world. The primary purpose of educational virtual reality (VR) environments is to provide a visual training platform that replicates the functionality of the real system being emulated. In this modified reality it is possible to train without the risk of serious consequences, explore the implications of actions and move beyond the bounds of reality to investigate the mechanics of an operation in more depth.

An educational system based on an immersive VR environment forms an application which is consistent with the merits of constructivist theory. Within the interface, a user is able to explore, investigate their surroundings and interact with software to develop and direct their own learning. The system provides a highly authentic representation of reality and supports an elaborate visual translation of concepts [31].

Joseph [32] discusses the educational benefits of immersion in VR environments. The experience is psychological because you have a true sense of "being there". This form of experiential learning is demonstrated to be associated with better concept retention as the learning can be relayed from a true first person perspective. Because the learner is immersed in the environment and able to truly experience the environment, there is evidence of heightened levels of enthusiasm, engagement and excitement. Through the application of a VR immersive environment it is therefore possible to overcome motivational hurdles and open up many avenues for learning opportunities. Being able to experience reality without suffering any consequences also stimulates a sense of fantasy and adventure because risks have been removed. This encourages students to perceive the learning differently and adds a level of fun and novelty to the experience. Joseph calls this edutainment—education occurring where technology and entertainment collide.

There are also cognitive load benefits. As the visual imagery is directly available to students, their cognitive processing demands are reduced. Interpretational difficulties can also be avoided by application of VR technology. In these environments, information is presented and accessible through the evolutionary prepared channels of visual and perceptual experience. Other methods of presentation such as graphs, charts and symbolic representations require a level of pre-knowledge to be interpreted successfully.

The technology extends 3D computer graphics into another sphere, providing a powerful platform for the development of more natural and intuitive HCIs [33]. Unfortunately there is too much focus on usability issues and improving 3D imagery and not on how best to select and integrate media to support the interactions and activities required. When creating VR interfaces designers should be controlling the balance between realism and usability and determining what level of immersion is appropriate for the concept being discussed. These issues should drive the development of the interface over and above what is technically possible [34].

Because the use of immersive VR technology in education is in its infancy, there is currently little guidance on virtual environment design. Scaife and Rogers [34] detail an approach which offers strong alignment with the strategies we intend to employ in the design of our interface. Their five stage approach considers aspects of educational theory, the range of technological possibilities and existing experiences prior to even establishing a development program. Before embarking on any prototyping, the project is clearly specified by defining educational objectives, performing learner profiling and studying appropriate methods of learning. From stage 3 on the learner is directly involved in the prototyping and user-testing phases. When the design has been finalised and a conceptual model developed, there is process for reviewing and evaluating the resulting virtual environment.

Our design approach mirrors this philosophy. Design decisions are based on key aspects of educational theory and follow proven educational approaches. We have looked at our target audience and profiled them to determine that VR with its visual learning benefits suit the learners. Other applications of VR in process engineering have been reviewed as well as other e-learning modes in a number of science based fields. We are now in the process of developing prototypes and performing usability testing cycles.

Evaluation

Key to the funding of this project is the ability to demonstrate the learning benefits offered by application of the immersive environment in engineering education. There are three aspects which we need to consider in evaluating this project:

1. The development process
2. Usability
3. Student performance improvement

To evaluate the development process, a process of review has been established. After key milestones have been reached in the project, the relevant development parties are brought together to revisit the process and determine its failings and strengths. Future effective strategies are agreed as a result.

Usability studies are performed by surveying small target groups. It is also planned to review and compare the users' and designers' conceptual model, observe first time users on cognitive walkthroughs and follow their navigation of the system using talk aloud methods.

Throughout the development of the interface, we have to continue to discuss how we measure the impact the tool has on learning and understanding in the field of engineering. Assessing student performance is complex because of its multi-dimensional nature. It is simple to break down the tool into its activity elements and assess each activity against its learning outcome by performing pre- and post- activity testing. However, there are holistic learning goals addressed and knowledge processing skills developed that will not be evaluated by this shallow form of assessment. In addition to an in-depth understanding of their field of study, we hope to have an impact on student's ability to communicate effectively, evolve as creative thinkers, make critical judgments and appreciate the ethical and social context in which they operate [35]. Measuring what impact this learning application can have on these higher level goals is the challenge.

VR ENVIRONMENT DEVELOPMENT

Goals

- Bring "real" plants to the university learning and teaching environment via a VR immersive environment. This provides a vehicle for students to view large scale operating processes without the hassles associated with visiting the site.
- Embed learning activities, tools and informative animations within the framework of the immersive environment to assist in teaching key aspects of the engineering curriculum including process design, operations, control and risk management.
- Structure the activities within each industrial environment to establish workflow and learning paths which develop concepts or build knowledge.
- Engage users and encourage meaningful learning by designing a platform for the immersive environment library which supports self-directed learning characterized by an innovative technology format such as a computer game, problem-based learning environment or an individualized method of mapping knowledge.

- Develop an assessment system which can qualitatively and quantitatively evaluate the impact the virtual reality (VR) immersive environment library has on the education of engineering students, both in terms of their general attributes and process engineering knowledge.

Outcomes

- A library of advanced VR environments for undergraduate engineering students and their industrial equivalents based on 3D photography of major operating processes.
- A set of learning activities covering aspects including process and equipment design principles, process operations, systems dynamics and risk management. These learning activities will provide an invaluable resource for the curricula within chemical and process engineering. Concurrently they form a very useful and practical resource for industrial operator and engineer training.
- A deeper understanding and targeted development of the most appropriate forms of visualization, computer-based educational activities and information resources to generate improved student insight into the design and behaviour of industrial process systems
- A qualitative and quantitative assessment of the understanding and insight generated through the use of the immersive system via specially designed instruments developed and co-coordinated by educational specialists
- A closer collaboration across chemical/process engineering departments in Australia who are participating in this project. Extensions to encompass other departments over the life of the project are also desirable.
- Stronger links with a number of major industrial companies supporting the further development of the library of immersive systems.

Immersive Environment Prototype

In the following sections we outline specific design preferences applied in constructing the BP prototype, as well as the activities already embedded in this system.

The focus of the BP prototype is the Number 2 Crude Distillation Unit (CDU2). Of the two crude units at BP (Bulwer Island) Refinery, CDU2 is the most recently constructed. It is the initial processing unit in the refinery and performs the first separation of crude oil according to boiling point. The key process operation in CDU2 is distillation. It is also characterised by a heat exchanger network called the preheat train, a preflash column, where the light fractions of crude are removed prior to the crude tower in an effort to reduce the size and capacity of the main tower, and a set of strippers, which perform quality improvements on the distilled products.

Software and Imagery: To aid in dissemination and widespread use of the system, a web browser delivery platform was chosen. All VR related work with embedded links was performed in LiveStage Pro software and the animations were developed using Flash technology from Macromedia. All work is done by professional multimedia experts and educational designers. Spoken materials were recorded with professional narrators [1].

The foundation for the interface is generated using spherical, digital, photographic images of the process plant. Many of the subsequent activities are overlayed on this environment. High definition spherical photography supports panning and zooming and other interactive features. Photography of CDU2 at BP was performed using professional industrial photography at some 19 nodes or locations throughout the plant spread over 3 vertical levels.

The functionality includes:

- Complete 360° spherical vistas of plant from a single observation point
- Ability to move through plant from one viewing point to another to create a “walk through” effect
- Zooming capabilities to focus on specific process equipment

Addressing Learning Outcomes: In consultation with the instructors and students, who would be end-users of the application, we were able to determine a set of needs that could be fulfilled by activities or information embedded in the virtual environment.

The environment was showcased to the lecturers in one-on-one sessions. In each of these sessions we presented the environment, demonstrated activities and information pieces already created in the prototype environment. These activities included taking a self-guided tour, a distillation phase behaviour animation and a pump isolation exercise. Apart from demonstrating the current multimedia development, this showcase was able to excite the lecturers and stimulate them to think of ways to use the environment within their own courses. This lead to discussions around tailoring applications for specific course needs. Once the need was identified it was possible to define that need in terms of learning outcomes. Hence we were able to form neatly defined applications to be created within the environment to address specific course learning objectives.

Learning Structure

With the integration of a number of immersive, industry-based learning environments into an educational library, two levels of structure have to be considered:

- The framework providing a repository for the information and activities within each industrial environment (Basic VR Environment Framework)
- The framework of an over-arching learning platform containing and linking all immersive learning environments and their activities through learning paths and conceptual similarity (Learning Platform Structure).

Basic VR Environment Framework: In applying a basic structure to each environment there are six main considerations:

1. Ability to extend the structure to other unit operations within the same plant and to other content based process engineering areas
2. Transferability to other processing engineering plant settings
3. Independence from site-specific terminology
4. Capability to grade activities according to their difficulty
5. Ability to allocate activities and informative pieces to a single repository
6. Simplicity of both development and use

To encourage self-directed exploratory research of the interface, a menu structure embedded in the VR has been selected for the base level environment structure. In investigating the VR interface, a learner can highlight all equipment with content or activity links associated with them. When the piece of equipment is selected, a right-click of the mouse accesses a description of that piece of equipment, learning resources associated with it or its system and a search page. Figure 2 depicts the current form of the search page. The search engine offers the ability for learners to follow links to learning resources classified by system variables such as portion of the unit covered, difficulty, subject area and learning objectives. Similarly a user can search through keywords to discover equipment, its features and location within the VR.

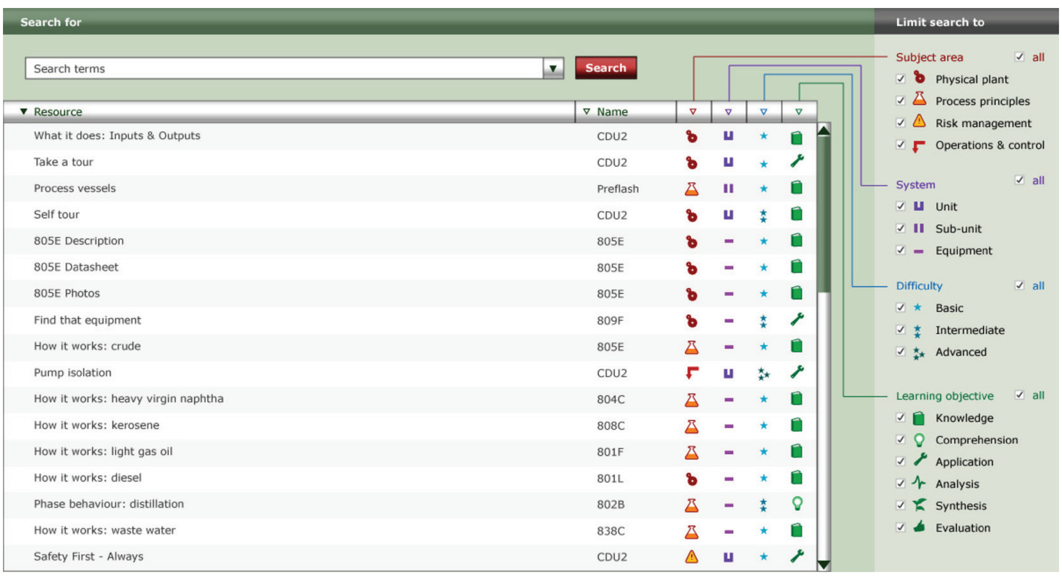

Figure 2. Search Page.

This structure offers the best utilization of the immersive environment's visual strengths. It also alleviates a menu structure, accessed external to the VR, with a branching structure with a number of unpopulated categories. In applying this structure, we are supporting functionality requested by students in usability surveys.

Learning Platform Structure: The learning platform has been judged on its ability to address the following aims:

1. to create an interface which supports self-directed learning; hence it has a web of learning paths through which concepts and conceptual difficulty build.
2. to frame information and activities in a system that is engaging and entertaining so learning is enhanced
3. to apply an interface that can be used within an internet browser platform
4. to use terminology and course language that is not university or site specific
5. to support a simple means of assessing the success of the learning tool against its stated learning outcomes
6. to develop a platform that has a low dependency on both hardware and software.

When a set of immersive environments has been developed, each employing the basic environment structure, we will look at ways to coordinate the environments into a self-directed learning platform characterized by an innovative technology format. The following different learning platform arrangements are under consideration for the library:

- A game-based philosophy—where successful completion of a task gives a user further power to acquire knowledge. There is an established set of pre-requisite skills required before embarking on certain tasks.
- A problem-based environment based on a day in the life of an engineer—users are confronted with an issue with plant operation or a daily operating constraint that they are asked to resolve or provide an alternate operating strategy to combat.
- A knowledge bank where users can deposit "tools" of the trade. In performing each task, users are asked to bank the concepts or "tools" that they have discovered, applied or appreciated during the activity. Within the bank, the tools are structured and linked within a concept maps generated by the user.

The computer game philosophy we are reviewing for use in this system employs a workflow approach which is slightly more advanced than that of CyberIST but not as complex as the evolving world of Atlantis in QA. Rather than making all the activities and information available at the start of the game, a workflow system coordinates their availability and completion by following a learning or concept path [18]. Within a game environment a learning path could be akin to a skill or ability like kicking in a traditional computer game.

In *Alien Rescue*, a science-based PBL environment where students are asked to explore our solar system for new planetary homes for six alien species fleeing their dying solar system cognitive tools are utilised to help students scaffold their learning [15, 36]. The development and application of these tools supported the creation of a cooperative constructivist learning environment where students were able to explore and digest information, explain their interpretation and compare and evaluate their understanding with others. Students take comfort in the fact that all the resources are available to assist them to solve the problem. In turn, their heightened level of confidence creates a supportive constructive knowledge building environment. Use of *Alien Rescue's* learning environment was demonstrably linked to a step-change in the student's understanding level and it was shown to support the development of a skill for life-long learning, that of self-directed problem solving [36].

These enviable results exemplify what we would like to achieve in our learning environment. Evolution of a learning platform around cognitive tools and a complex problem solving activity are possible in this setting. Authenticity of the task is guaranteed by the framing of the problem around real day-to-day plant issues. Real raw data is accessible through the partnership with BP Bulwer Island Refinery as well as design and datasheet information for the equipment currently being used. Translation of the learning environment into this problem based design is quite easily achievable.

The other learning platform option proposed would involve users performing activities, depositing the lessons learnt in the activities and structuring their knowledge into individualised concept maps within their own knowledge banks.

The final learning platform structure will probably apply different aspects of each of these three ideas. It is likely that prototype environments offering this functionality will be developed and introduced to students and industrial operators in the development stage (Stage 3) of this project. Through observation of their actions in the environment, a cognitive survey of their general attitude towards the learning environment and a questionnaire on the learning opportunities offered in the environment it is hoped that we can gauge how best to develop a learning platform to address the users needs.

Current Developments

Safety (PPE) Activity: To reinforce risk management principles and practices all users must complete an interactive plant induction that includes selection of appropriate personal protective equipment (PPE). Figure 3 shows part of that activity.

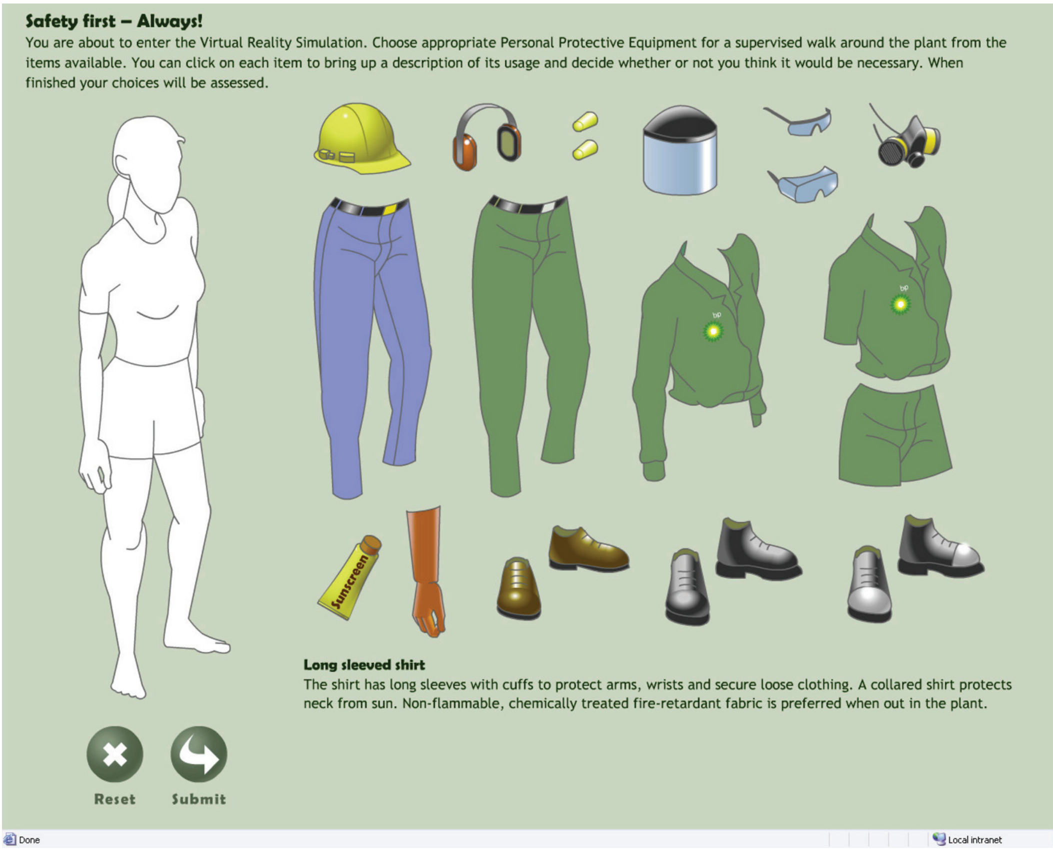

Figure 3. PPE activity for new users.

Video 1 Safety First  Safety First

By clicking on the "Safety First" video icon or link, actual footage of the activity in progress can be viewed.

Process Tour: Users are initially able to take a fully guided and narrated tour or they can choose to take a self-guided tour to move around the plant to any place of interest. Figure 4 shows a user embarking on a self-guided tour of the facility.

Figure 4. Self-guided process tour.

Video 2 Take a Tour Take a Tour

The "Take a Tour" video icon or link takes a user on an abbreviated narrated tour of the CDU2 unit.

Process Description: Users are able to choose certain products to follow through the process. A narration describes the product's journey and graphics are animated to show the product's path. The current animations (Figure 5) show the temperature profile as materials flow through the process equipment, such as that for crude oil. A narration also describes the passage of the product.

Figure 5. Crude oil process pathway.

Video 3 How it Works—Diesel How it works - Diesel

A process description detailing how diesel is produced within the unit is revealed in the video clip, "How it works—Diesel".

Other activities at this level involve equipment identification tasks across the plant and basic navigation through the unit for familiarization. A process flowsheet (Figure 6) is also available for user reference. This depicts the product streams in different colours and shows how these product streams interact with the major pieces of equipment.

The following two activities are considered to possess higher level interactivity and complexity than the previous exercises. Activities within this category take a deeper and more fundamental view of part of the process by focusing on major aspects of process engineering or alternatively, evolve from operational requirements for key pieces of equipment. They are characterised by higher level user participation or a multi-layering of concepts.

Distillation Phase Behaviour: The distillation activity focuses on the pre-flash sub-unit of the crude unit which has the goal of reducing the quantity of low boiling point materials in the crude feed to the main crude tower. Figure 7 depicts this unit and its ancillary equipment as viewed in the VR tour.

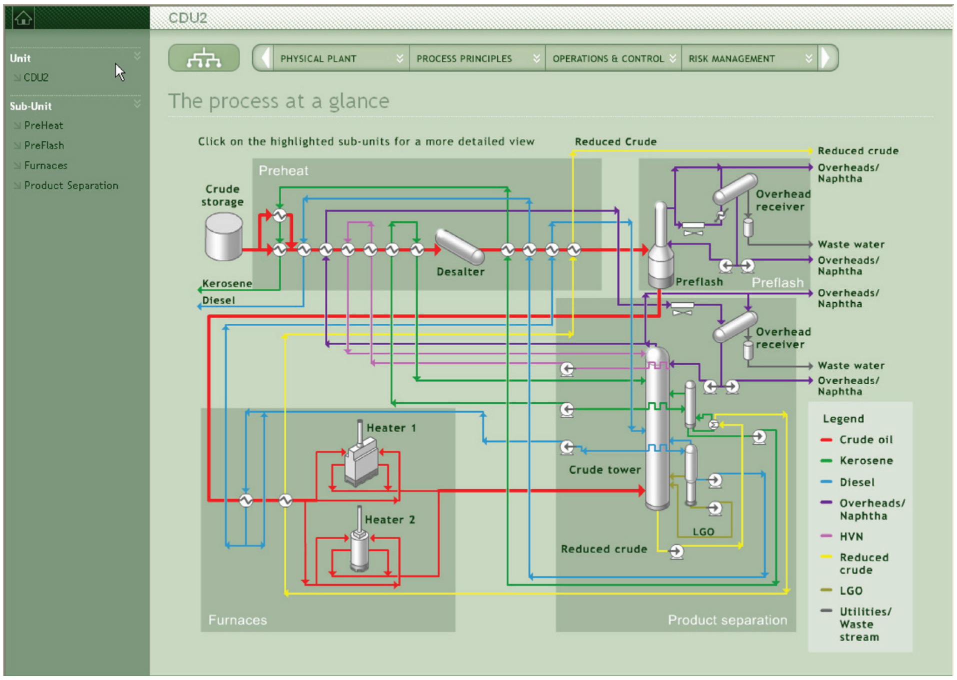

Figure 6. Overall process flowsheet.

Figure 7. CDU2 Preflash sub-unit.

Coverage of the Preflash sub-unit includes:

- A definition of process vessels and their application in the refinery
- A process flow diagram (PFD) isolating the Preflash unit
- Process and instrumentation diagrams (P&ID) displaying a symbolised view of the unit and its controls.

Armed with these information resources, the user can get a complete picture of a functional distillation unit. With this focus a student can appreciate the scale, complexity and detail of this form of separation. Learners can also translate the theory of distillation into operation. They can see how a temperature profile is established across a column, how access and layout issues are handled, view operating pipework and control systems and understand the network of product draws at multiple heights on the column.

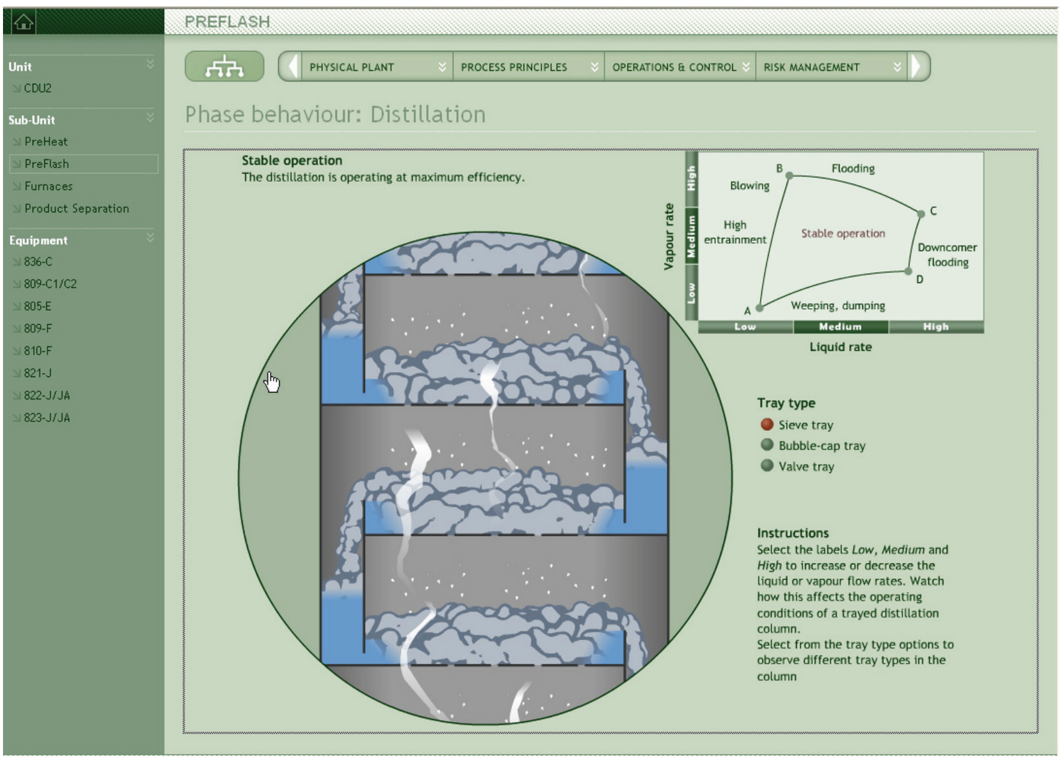

Figure 8. Distillation phase behaviour.

Video 4 Distillation  Distillation

The key process engineering concept in focus within the preflash column is distillation. An informative animation (Figure 8) explores the theory of distillation in more detail. Within this activity a user can manipulate vapour and gas flows and tray type and see the effects that this has on liquid-vapour contact regimes. Dynamic models of distillation have been formulated to enable students to manipulate key system variables and assess responses. These are still to be linked to the VR.

The animation and its manipulation can be viewed by clicking on the video link called “Distillation”.

Pump Isolation Activity: The pump isolation exercise (Figure 9) exemplifies the use of GRAFCET diagrams to manage a procedural task [37]. In this activity, users perform a pump shutdown by mimicking all the actions required within the VR environment. By turning valves, securing spare pumps and opening drains, the user appreciates the detail required by the procedure and the critical importance of each step. They are also able to realise the checking mechanisms and the regimented correctness facilitated by the GRAFCET structure.

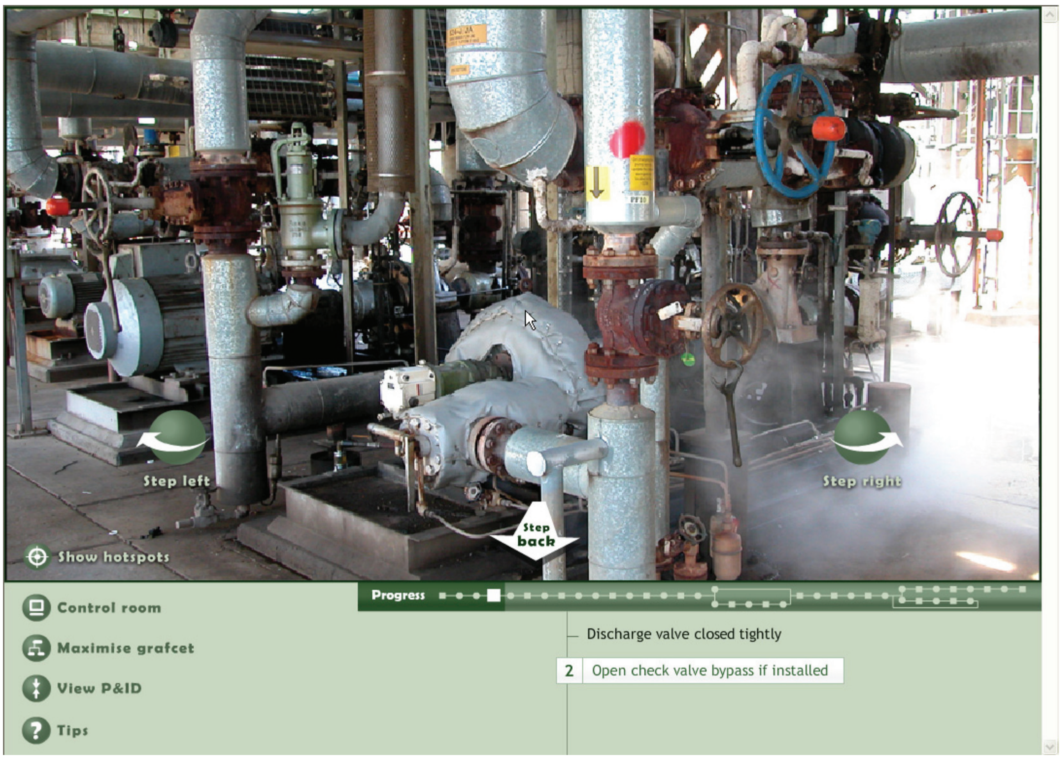

Figure 9. Isolation activity.

Video 5 Pump Isolation Pump Isolation

Operationally, a user gains a better appreciation of aspects that they may have to consider when designing such a system. For example, they have to incorporate drains, spare pumps and utilities that facilitate taking the pump out of service for maintenance. Valves have to be accessible and pump systems integrated and duplicated so that tasks such as a pump shutdown are performed easily and consistently. Simply providing access to visual graphics of a real operational pump and its ancillary equipment is sufficient to enlighten students on the relative size, shape and feel of a process plant.

To a plant operator, the level of training offered by the pump isolation exercise is unsurpassed. Unaffected by weather, time of day, risk of wrongdoing and without requiring strict supervision, a novice operator is able to practice his or her craft. In reality, pump shutdowns are infrequent; hence operators lack procedural practice. This virtual environment offers operators the ability to practice shutting down a pump without disrupting plant operations. A repetitive process such as a pump shutdown is rudimentary but without room for error; hence it is ideally suited to a VR based activity programmed using the GRAFCET philosophy. This program facilitates a consistent level of teaching from a simple internet platform without requiring resource intensive training regime.

A video snapshot of the activity in progress has been created and can be viewed by selecting the Pump Isolation video icon.

P&ID to VR Referencing: From the process and instrumentation diagram (P&ID), a user is able to select a piece of equipment. This referencing tool then links this equipment symbol to its VR image. When you re-click on the piece of equipment in the VR, it will return to the P&ID highlighting the equipment's symbol as depicted in Figure 10. In this way the learner builds an understanding of the 2D representation and its relation to the 3D physical world.

Future Developments

The following five activities are all still being formulated:

- A flow-sheeting exercise
- A mass and energy balance activity
- A GRAFCET diagram application
- An activity developing temperature vs enthalpy (T vs h) charts
- A wonder-why tour
- An explosion simulation case study

Each of these activities have clearly defined learning outcomes and are associated with assessment pieces designed to determine whether the knowledge has been successfully transferred by use of the

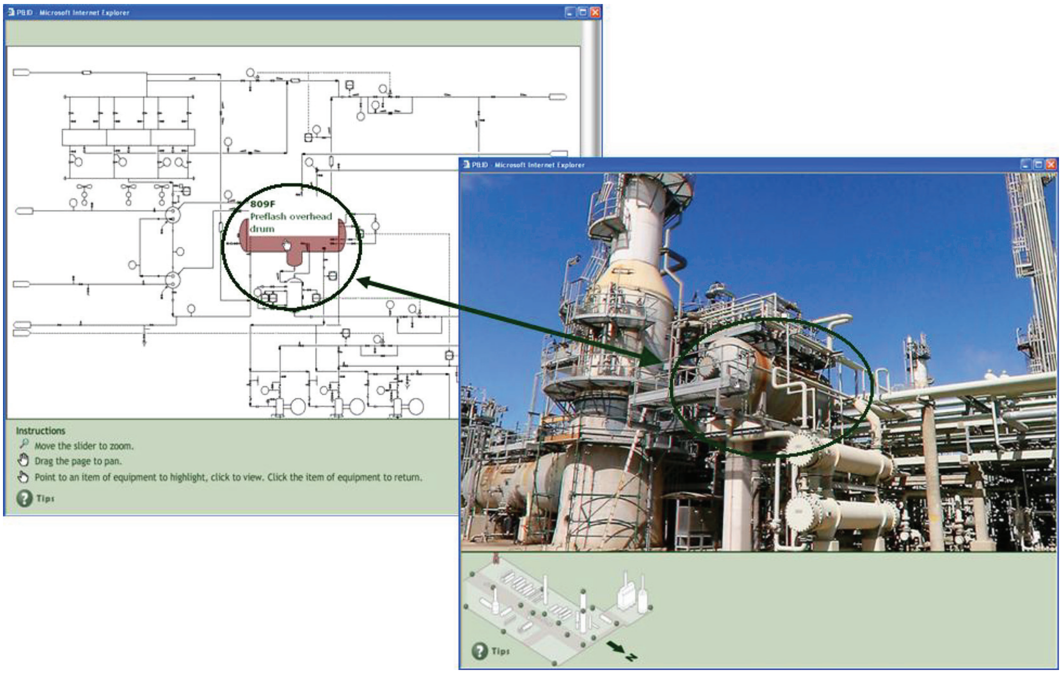

Figure 10. P&ID to VR Referencing.

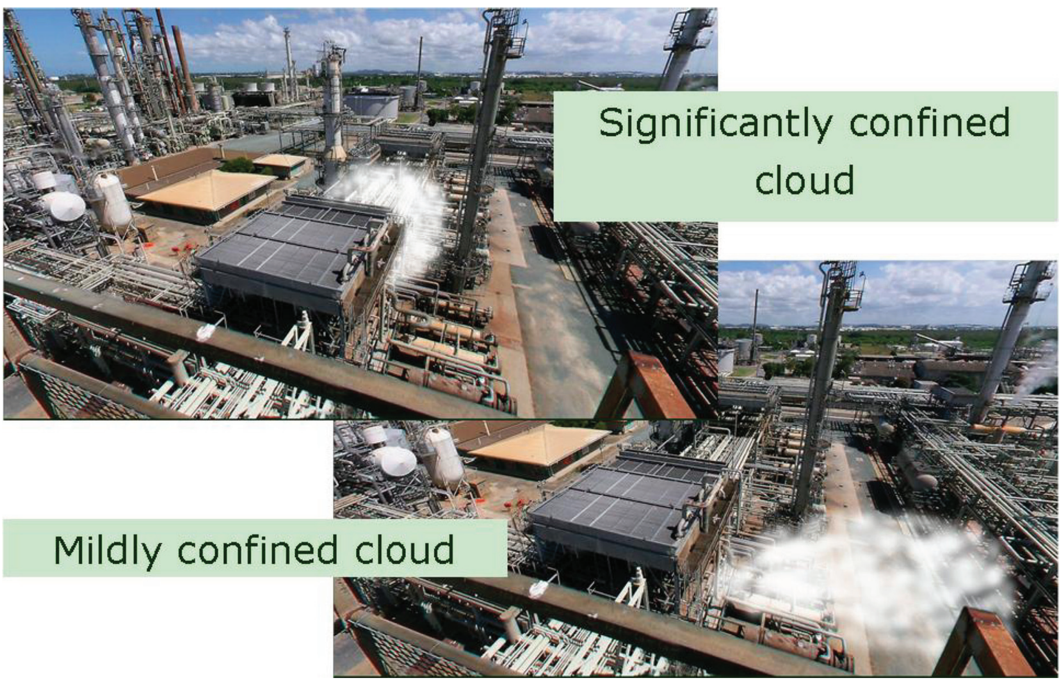

Figure 11. Explosion Simulation Case Study Development.

application. The applications have to be carefully designed to make them amenable to computer use within an internet platform. Free-hand calculations or drawings are difficult to perform within such an environment so most of the activities are based on picking and placement from a set of options.

Flow-sheeting: Re-translation of an operating plant into its rudimentary flowsheet form is an exercise of value when checking design decisions and performing hazard analysis. Here, the learning outcome associated with the flow-sheeting exercise is defined in terms of an Engineering Process objective:

Be able to synthesise a process flowsheet in terms of input-output structure, recycle systems and reactor or separation vessels from a process description.

The activity involves listening to the narration of each stream specific process description and colour coding a process flowsheet template. Students are also asked to annotate the equipment, streams and process sections from a provided list of labels to create an overall flowsheet as depicted in Figure 6.

Mass and Energy Balance: This piece of work has a two-dimensional learning outcome covering Complex Reasoning and Engineering Process:

Be able to identify the process variables from a problem description and construct appropriate mass balance and energy balance equations in order to solve the problem.

This activity is framed as a problem solving exercise. There is a visible quality issue with a diesel product, and the student is asked to investigate. An assistant guides students through a set of queries or statements which focus the student in on the piece of equipment causing the problem. There is in fact a hole in an exchanger, but to determine which exchanger needs to be taken out of service for repair, both mass and energy balances have to be performed on the system.

GRAFCET Diagram: This activity focuses on the needs of an advanced control course generally taught in the later years of study; hence the desired learning outcome is multi-dimensional addressing Engineering Knowledge, Complex Reasoning and Engineering Process objectives:

Recognise a discrete event system and design a control system for a shutdown using GRAFCET.

Having identified that an exchanger is to be taken out of service, the task is to create a procedure, using GRAFCET, to safely shutdown, drain and isolate this piece of equipment. The GRAFCET template is available on the screen and the student is required to order the steps correctly and associate each step with the appropriate check.

T vs h Charts: This is a simple exercise designed to form part of the introductory course. It has a rudimentary objective covering Engineering Process skills:

Be able to use phase diagrams to describe a system and plot relevant thermodynamic cycles and paths on T vs h charts.

The task involves following the path of a molecule of kerosene through a crude distillation tower and mapping its associated thermodynamic path on a temperature versus enthalpy plot.

Wonder Why Tour: This activity is designed to focus students in on the detail of the plant. It exercises discovery learning behaviour best encapsulated by an Engineering Knowledge objective:

To visualize key equipment, in a real engineering setting and gain an understanding how each piece of equipment works and what purpose it serves.

The student wanders the virtual environment exploring the intricacies of the design. The focus is drawn to small elements of the plant that might otherwise go un-noticed but play an important role in the process environment. Through this discovery, it is hoped that some of the questions that the students may have had had they actually visited the site may be addressed. At each node there is something of interest that prompts a discussion with the Einstein professor, an animation showing its operation or a view of the cut-through for further analysis.

Explosion Simulation Case Study: Hazard management and risk mitigation exercises are frequently overlooked in process engineering education. This exercise is designed to highlight considerations needed to be made when designing a system processing highly flammable and explosive chemicals. It also reviews real catastrophic failures in petrochemical processes, focusing on human, economic and environmental impacts of the disasters. The objective of this case study has Engineering Knowledge and Engineering Process components:

To analyse a system design to review the role of confinement in explosions and to explore design considerations made to mitigate and control such hazards. Simultaneously highlight the real impact of process system failures to students.

Figure 11 shows two flammable gas clouds that can be generated within the proposed explosion simulation case study to illustrate the role of confinement. The simulation then models the effects of an explosion of the constructed gaseous clouds.

CONCLUSIONS

Usability surveys completed by university students have provided key feedback on the current system functionality as well as areas for improvement. A summary of survey responses collated by Birtwistle and Barnes [38] identifies the following issues:

- Disorientation: around 55% of users surveyed found themselves disorientated in the virtual environment at some stage. They were unable to determine which direction they were facing.
- Challenge: students in their 3rd, 4th and 5th years of study found most of the activities too easy.
- Interaction: activities with high levels of user interaction provided more stimulation to the students and were more engaging.
- Narration: a large proportion of students surveyed considered the narrator to have a monotone, boring voice which they didn't find captivating.

Future work on this project will resolve these issues. To address the issue of disorientation, the project team is looking to bed a new VR software system which supports the creation of a compass. This compass would rotate according to the position of the user, to inform them of the direction they were facing. With the inclusion of the extra five activities in the interface, we hope to provide more challenge for those students in their final years of the course. In particular, the Mass and Energy balance exercise along with the GRAFCET creation activity have difficulty levels pitched at these students. All new activities are highly interactive, offering students opportunities to manipulate and create solutions within the learning tool. Future developments will consider the tonal variety of the narrator selected; however, we will retain this narrator for those activities already developed.

Comments from students have indicated that the prototypic basic environment structure used to house the VR and embedded activities, although easy to navigate, has a number of blank heading selections, which have no activities or content associated with them. This is irritating to a user. Users have also flagged a need for classification of the activity's difficulty and conceptual complexity. This has been addressed in our selection of the menu system housed in the VR along with an appropriate search engine classifying activities characteristics in terms of subject area, system designation, difficulty and learning goals.

Lecturers and representatives of our partner universities have encouraged us to align our activities with the strengths of the VR. Those activities that are heavily reliant on the VR imagery and enhanced by the immersive environment should be our focus. Other activities, without this VR interactivity may be better performed in another interface.

Progress on the learning platform is limited by the pace of development of new immersive environments in the library. Until the scope of the library has been finalised and the activities created in each process environment, there is limited opportunity to devise the form of this platform.

Evaluation at this stage of the project should focus on the development process and usability issues. Student performance improvement is an aspect of evaluation that should be considered later in the project.

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