Bringing Industry into the Classroom: Virtual Learning Environments for a New Generation

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ABSTRACT

Engineers need to be practical, but potential litigation, cost and logistics all act to frustrate efforts to provide undergraduate student engineers with practical experience of industrial facilities. The long timeframes of major engineering projects also mean that students often see only a snapshot of the entire project life cycle. A partial solution is to attempt to bring industry into the classroom through virtual learning environments. This study aims to measure student perceptions of the effectiveness of virtual reality environments in enhancing their understanding of the design and operation of industrial facilities. The six virtual learning environments developed by the authors to date are briefly described. They are all created around a linked collection of high-resolution spherical photographs, and the plants include an oil refinery, a water recycling plant and a tank farm. Significantly, three of the environments are 4D, meaning that they capture some aspect of the evolution of the plant over time. The typical activities that students undertake within the learning environments are discussed and linked to CDIO attributes. Qualitative and quantitative assessment techniques were used to measure student perceptions of the usefulness of the virtual environments in two chemical engineering subjects, 2nd year Process Heat Transfer and 4th year Risk Management. In Risk Management, a pre/post test showed that students identified significantly more hazards when using the virtual environment compared to an engineering drawing. For both subjects, students gave very positive responses, 85% agreement or above, about the usefulness of the environment in enhancing their knowledge of industrial plants, having a helpful effect on learning, and enriching their learning through linking plant images with corresponding technical diagrams. Significant differences in the perceptions of the two student groups were observed for the ease of use, enjoyment, and ability to visualise the size and positioning of industrial equipment. Analysis of free text comments identified areas in need of further development.

KEYWORDS

Virtual reality, engineering education, learning environments, design, system thinking.

INTRODUCTION

Within university, undergraduate engineering students often lack industry exposure. Opportunities for providing a visual context for process theory in real operating systems are increasingly less accessible to students. Costs and litigation concerns, as well as logistic constraints, make both plant operators and university staff hesitant to conduct large scale plant tours [1].

The timescale of many major projects also means that engineering students rarely get the opportunity to experience and understand the complete life cycle of a major engineering design, be it a structure, machine, network or a process. This leaves a significant gap in the conceptual understanding of today's process engineering undergraduate.

Engaging students effectively across all the life cycle stages is therefore extremely difficult in education environments. Engineering educators need novel ways of engaging students with the life cycle stages, contextualizing design and operations, and understanding the important interactions that exist at all levels within the larger design picture. Students need to understand the important decision-making processes that accompany life cycle issues and key socio-environmental conditions.

This paper describes a suite of novel learning environments, based around real industrial processing plants, that capture the thinking and reasoning around engineering designs across all stages of a project, from the identification of a need through to the retirement of the project. These environments enhance students' insight and understanding by providing [2]:

- A real engineering context within the different plants;
- Relevant activities and information packages embedded within virtual reality (VR) imagery;
- Exploratory platforms to discover and investigate at the individual's own pace.

The paper also explores the initial results of the classroom implementation and assessment of the learning environments in two subjects.

DESCRIPTION OF THE LEARNING ENVIRONMENTS

The virtual learning environments are software programs that run on standard PCs. They are based around a collection of high resolution spherical photographs taken at multiple locations around several industrial facilities. The photographs are supplemented with information on the plant equipment, animations, diagrams, videos and activities for the user. While the environments are still under development, they have been used already for industrial training and university teaching. They are briefly described below. Further information is provided in [3], [4] and [5].

Most of the virtual environments have a common main menu with four choices:

- **Explore the plant** consists of
    - A linked collection of high resolution spherical photographs at multiple locations (nodes) around the plant that can be panned, tilted and zoomed;

  - Hotspots within the photographs that allow the user to jump to an adjacent node, or to explore extra resources, such as plant diagrams, available for a particular equipment item;
  - A "mini-map" of the plant below each spherical photograph that shows the user's current location and orientation.
- **How the plant works** is comprised of a series of narrated animations that describe the function of the whole plant and its main subunits.
- **Activities** are specific to the plant in question, but may include plant induction and safety videos, a narrated guided tour through the plant nodes, and so on.
- **Plant diagrams** consist of a collection of professional engineering and schematic drawings, including process flow diagrams, Piping and Instrumentation Diagrams (P&IDs), plot plans and simplified schematic depictions of the process.

The six learning environments created to date are compared in Table 1. The first environments that were developed captured the state of mature plants at a particular time. Figure 1 shows several views from the BP Refinery environment, which was the prototype. The more recently developed environments are "4D", capturing some construction activities over time. This can be seen in Figure 2, which illustrates the installation of equipment in the City West Water environment. The time slider, which is visible in the bottom left hand corner of the images in Figure 2, is used to step through the time sequence of photographs at a particular node.

Table 1
Comparison of virtual learning environments

Environment	Description	Selected features
BP (Bulwer Island) Refinery	Crude distillation unit of an oil refinery located in Brisbane	• 42 nodes on several vertical levels • Interactive visualisation of phase behaviour in a distillation column • GRAFCET-based pump isolation activity • Find that Equipment activity
Coogee Energy Methanol Plant	Natural gas to methanol plant in Melbourne	• 49 nodes on four vertical levels • Hotspots providing information on more than 300 equipment items, ranging from the main reactors and distillation columns to individual valves
PTA Tank Farm (Pinkenba)	Tank farm with eight new liquid storage tanks located in Brisbane	• 4D environment: 19 nodes imaged ten times during the eight-month construction period of the new tanks • Selected high resolution images and videos • Video interviews with key engineering and management personnel
City West Water Altona Water Treatment Facility	Water recycling plant featuring four ultrafiltration units and five reverse osmosis trains located in Melbourne	• 4D environment: up to 26 nodes captured 16 times over 11 months during the construction of the facility • 77 nodes imaged in the completed facility • Over 2100 plant items catalogued and described
BP Northpoint Weighbridge	Large truck weighbridge in Melbourne	• 4D environment: Six nodes imaged every two days during the construction of the facility
Boya Quarry WA	Small quarry located east of Perth	• Used for knowledge transfer • Three nodes

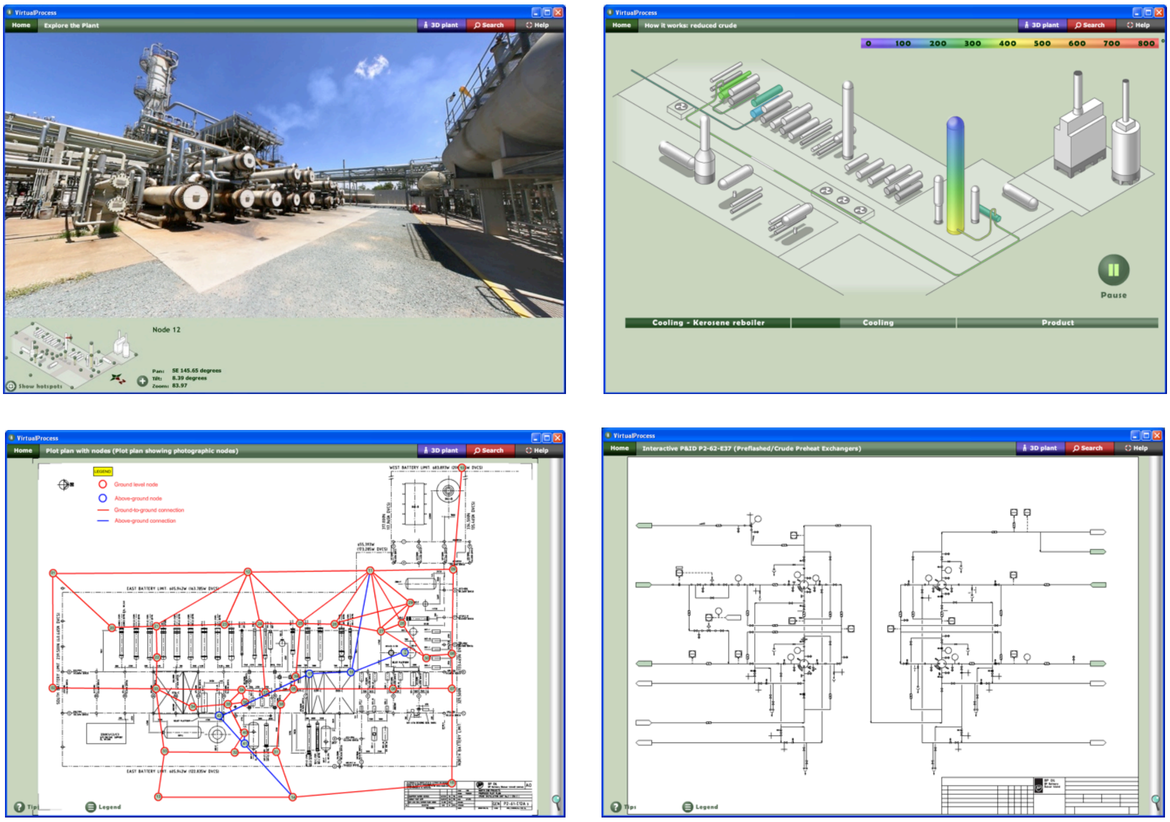

Figure 1. Four views of the BP Refinery environment (clockwise from top left): high resolution spherical photograph with mini-map showing the current location; animated “How it works” description of a plant area; piping and instrumentation diagram of four heat exchangers; plot plan showing ground-level and above-ground node locations.

Outside NW corner of building
Pan: NE 40.57 degrees
Tilt: -11.32 degrees
Zoom: 91.69
May 19 2010

Outside NW corner of building
Pan: NE 40.57 degrees
Tilt: -11.32 degrees
Zoom: 91.69
Jul 28 2010

Outside NW corner of building
Pan: NE 40.57 degrees
Tilt: -11.32 degrees
Zoom: 91.69
Sep 17 2010

Outside NW corner of building
Pan: NE 40.57 degrees
Tilt: -11.32 degrees
Zoom: 91.69
Apr 4 2011

Figure 2. 4D time sequence of the installation of degasification towers in the City West Water environment, starting in May 2010 (top left) and finishing in April 2011 (bottom right).

EDUCATIONAL OUTCOMES OF THE LEARNING ENVIRONMENTS

Teaching staff are able to use the environments within the classroom as a powerful visual tool to illustrate the challenges of systems thinking, design, interdisciplinary activities and resource management for construction and commissioning [3].

Students using the learning environment are able to develop key Engineering Skills and Attributes through:

- *Experimentation, Investigation, Knowledge Discovery and System Thinking (Thinking Holistically, Emergence and Interactions in Systems)* while they:
  - Experience the time progression of a design–construction–commissioning sequence as a real processing facility is being designed and built;
  - Investigate the construction evolution of a particular spatial area through time by moving forward and backwards in the time frame to help understand the interdisciplinary aspects of engineered systems;
  - Move within a specific time zone to discover the issues related to complex system interactions within the process.

- Principles of *Conceive, Design, Implement and Operate Systems in the Enterprise, Societal and Environmental Context* while they:
  - Understand how engineers from a range of disciplines work together on key issues and the range of decisions required for that part of the design;

- Discover the wider interactions that engineers have with other disciplines, such as government planning agencies, consultants and regulators during major projects;
- Investigate and understand important interdisciplinary concepts and practices;
- Study particular crucial design decisions – aided by interviews with key engineers explaining how decisions were reached;
- Understand the roles that all the different project personnel play, whether professional engineers or not, in the design, construction, commission and operation of the processing facility;
- Participate in activities that take the students beyond the processing facility to consider how it might be extended or expanded;
- Appreciate the important areas of safety, sustainability and community relationship management that over-arch all stages of the project;
- Access, interpret and understand a wide range of facility drawings (process, civil, mechanical, electrical).

All these outcomes can be achieved on the student's own computer, allowing them to experience real sites remote from their own institution. The environments will also permit those students with physical disabilities, such as impaired mobility, to participate equally with more agile students in this exposure to industrial engineering design practice.

EDUCATIONAL IMPACT EVALUATION

Qualitative and quantitative assessment techniques were employed to measure the perceived usefulness and learning related to the VR environment. Two examples of the implementation and assessment of learning outcomes and students' perceptions of learning at Curtin University are provided in this section.

Process Heat Transfer (PHT)

Process Heat Transfer is taken by chemical engineering students in the first semester of their second year in the course. Two particular heat exchangers located in the BP Refinery, which are visible in the four images of Figure 1, were used as the basis for several activities:

- Identifying the role that the exchangers played within the plant;
- Locating the two exchangers on photographs, a plot plan and a P&ID;
- Calculating the variation over a year of operation of three exchanger performance indicators – the duty, overall heat transfer coefficient and fouling factor – using real data captured from the BP plant control system and information from the exchangers' equipment specification sheets;
- Interpreting the trends in the performance indicators;
- Predicting the performance of the exchangers for standard operating conditions, but with different levels of fouling.

Anecdotal evidence suggests that the students appreciated the opportunity to work on a "real life problem" and with operating data from an industrial facility.

Risk Management (RM)

The BP Refinery environment was also used by fourth year chemical engineering students in Risk Management. The students performed a hazard identification (HAZID) exercise, in the form of a pre/post test. Hazard identification is a key engineering concept that applies at the conception, design and operating stages in order to ensure that risk is kept as low as reasonably practicable. The main objective of the hazard identification test was to identify hazards related to the maintenance of a certain piece of equipment (pump or column) by firstly using only a piping and instrumentation diagram, and then performing the same task by looking at the piece of equipment in the VR environment.

Quantitative and qualitative results

The RM pre/post test clearly shown a significant difference between the students' understanding and identification of hazards when using a P&ID compared to using the VR environment. Table 2 shows the initial and additional hazards identified in this process.

Table 2
Hazard identification on the process of maintenance of a refinery pump and column

Hazards identified by using the piping and instrumentation diagram	Additional hazards identified by using the virtual plant
Thermal (burn)	*Limited space between the pump to be serviced and the spare pump*
Chemical (contact, leaks, spills)	*Scaffolding present next to pump – physical hazard (tripping, falling, limited space)*
Pressure (stored energy, blocked valves)	*Structural supporting elements not mounted to the ground*
Sources of ignition	*No emergency eye-wash/shower near the units*
Incorrect isolation/operations of valves	*Working at heights*
	Visual impairment/restrictions

This activity was designed to communicate the differences between what is shown on an engineering diagram and what actually exists on an engineering site. It has the potential to broaden the students' understanding of engineering design and facilities in terms of the risk management strategies involved and to encourage them to consider what cannot be viewed on a piece of paper. This in turn could produce superior chemical engineering graduates who have a knowledge balance between theory and practicality, and are more aware of the hazards and risks associated with construction and processing sites. This better understanding would benefit themselves, the company they eventually work for and society.

The students were also asked to complete a questionnaire assessing the functionality and ability of the virtual environment to enhance aspects of their learning and understanding of process heat transfer and hazard identification techniques. The questionnaires consisted of twelve statements about which the students were required to rate their agreement. Ratings ranged from 1 to 4, with 1 indicating strong disagreement, 2 disagreement, 3 agreement, and 4 strong agreement.

Table 3 shows the correlation between the RM and PHT classes for each of the twelve quantitative questions asked in the survey. From these data the following can be concluded:

- RM students found using the virtual refinery more enjoyable than the PHT students.
- The students in PHT found the system easier to use than the RM students.
- The RM students found that the system helped them visualise the size and positioning of industrial processing equipment more than the PHT students.

These differences might relate to the position of the students in their course (year 2 vs. year 4), previous experience (the students in year 4 have generally had the benefit of two months of industrial experience) and the actual task required.

Table 3
Item mean and standard deviation for class differences in students' perceptions of Risk Management and Process Heat Transfer measured by the questionnaire scales

Question	Class	Mean	Std Dev.	t
1. The VR Experience was enjoyable.	RM	3.04	0.548	1.997*
	PHT	2.84	0.741	
2. The VR system was easy to use.	RM	2.65	0.592	-2.739**
	PHT	2.91	0.741	
3. Finding VR activities on desired topics was easy.	RM	2.79	0.541	-0.667
	PHT	2.85	0.725	
4. Performing VR activities was easy.	RM	2.71	0.550	-1.229
	HT	2.83	0.752	
5. VR activities enhanced my knowledge & understanding of industrial plants.	RM	3.00	0.621	-1.450
	PHT	3.15	0.760	
6. The VR experience confirmed my interest in chemical engineering.	RM	2.79	0.766	-1.068
	PHT	2.91	0.790	
7. The link between imagery & technical diagrams enhanced my learning.	RM	3.14	0.584	1.088
	PHT	3.04	0.677	
8. The VR was useful to my learning.	RM	3.04	0.538	-0.764
	PHT	3.10	0.640	
9. The VR was useful in helping me understand hazard ID/HX use in industry.	RM	2.88	0.692	-1.675
	PHT	3.05	0.739	
10. The VR helped me visualise the size, positions & environment of a pump/HX in oil refineries.	RM	3.31	0.640	4.425***
	PHT	2.85	0.772	
11. The VR improved my understanding of equipment design.	RM	2.98	0.624	1.430
	PHT	2.83	0.783	
12. The VR provided context for the question.	RM	2.92	0.666	-1.651
	PHT	3.10	0.816	

**p*<0.05, ** *p*<0.01, ****p*<0.001; RM (n=84), HT (n=116).

Figures 3 and 4 present the results obtained from the quantitative questions asked in the questionnaire.

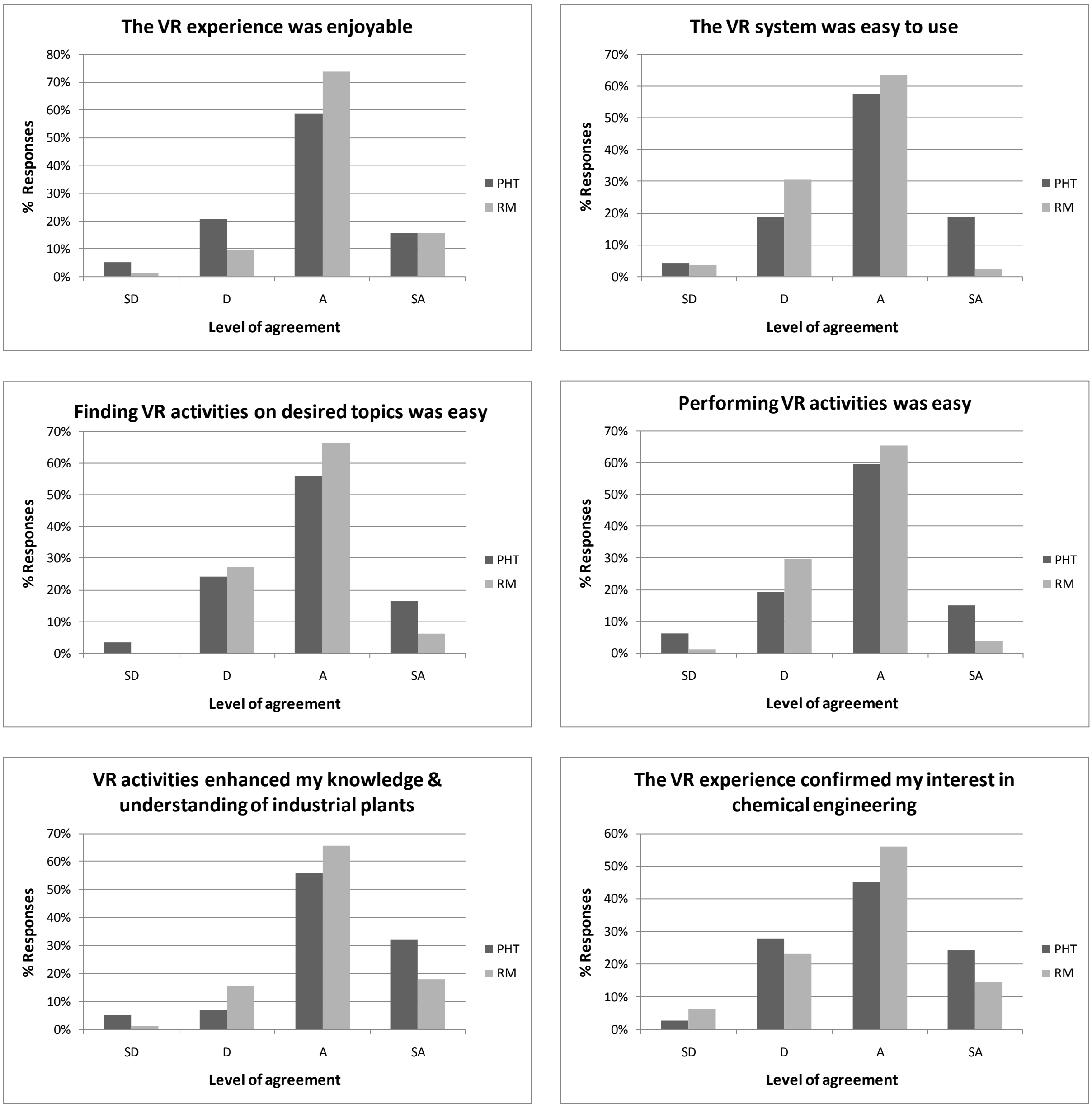

Figure 3. The questionnaire results for questions 1 to 6.

The results indicated that:

- Extremely positive responses were achieved regarding the usefulness of the VR environment in enhancing students' knowledge of industrial plants (85%) and having a helpful effect on their learning (86%);
- The links between the imagery and the technical diagrams were found to enrich students' learning (87%). This was also supported by the strong link between 'useful' and 'plant diagrams' in the qualitative analysis shown later;
- 80% of the students felt that the VR was used in the right context of their assessment.

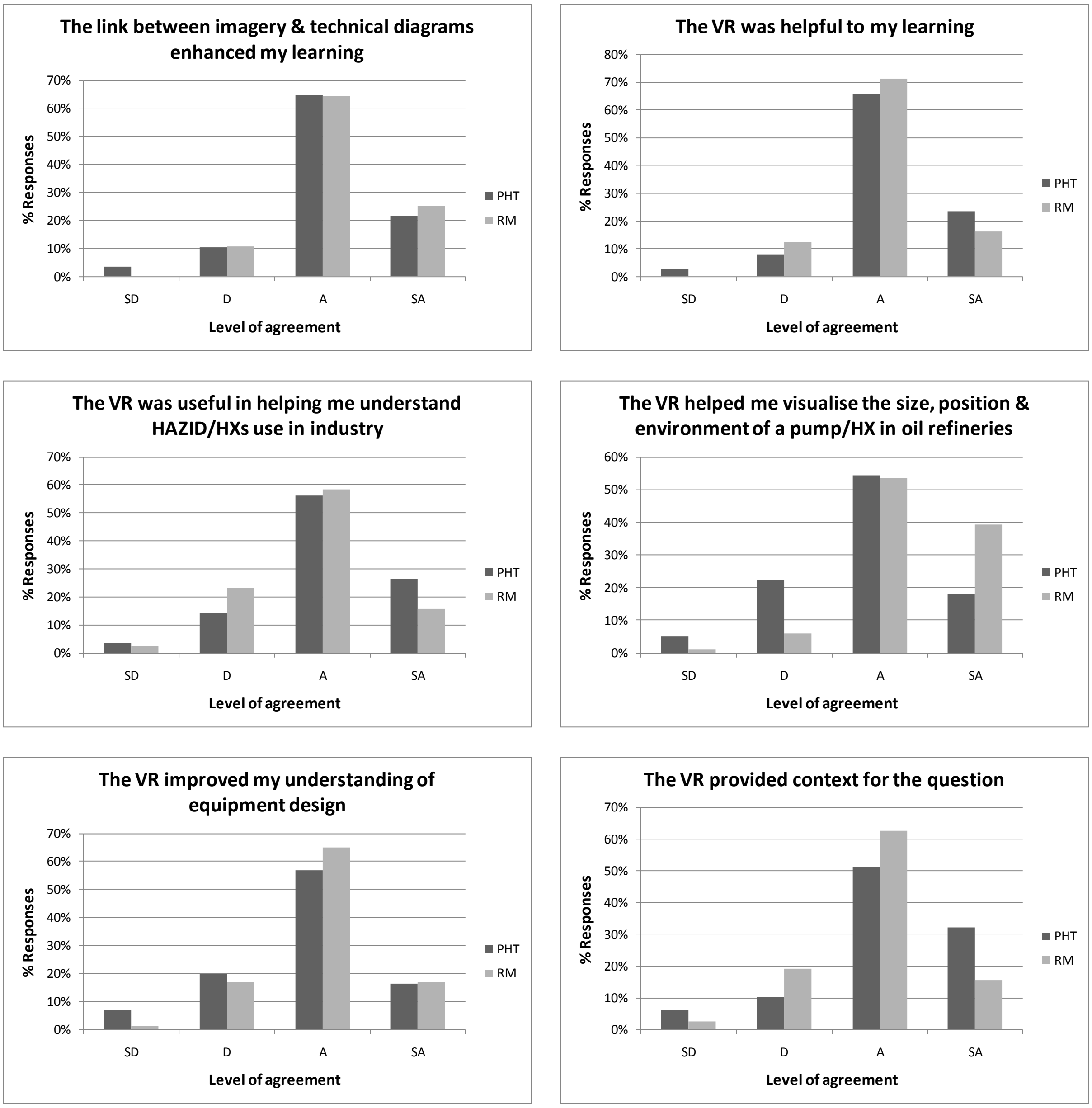

Figure 4. The questionnaire results for questions 7 to 12.

The questionnaires also incorporated qualitative questions concerning what the students found least and most useful about the VR software, and what aspects required the most improvement. Figures 5 and 6 were created based on these comments and using IBM SPSS software. The software produced a keyword database and similar keywords were grouped together. The category webs formed display the relationships between the different keywords and the frequency of their occurrences. For the purpose of this experiment, the PHT and RM results were considered together.

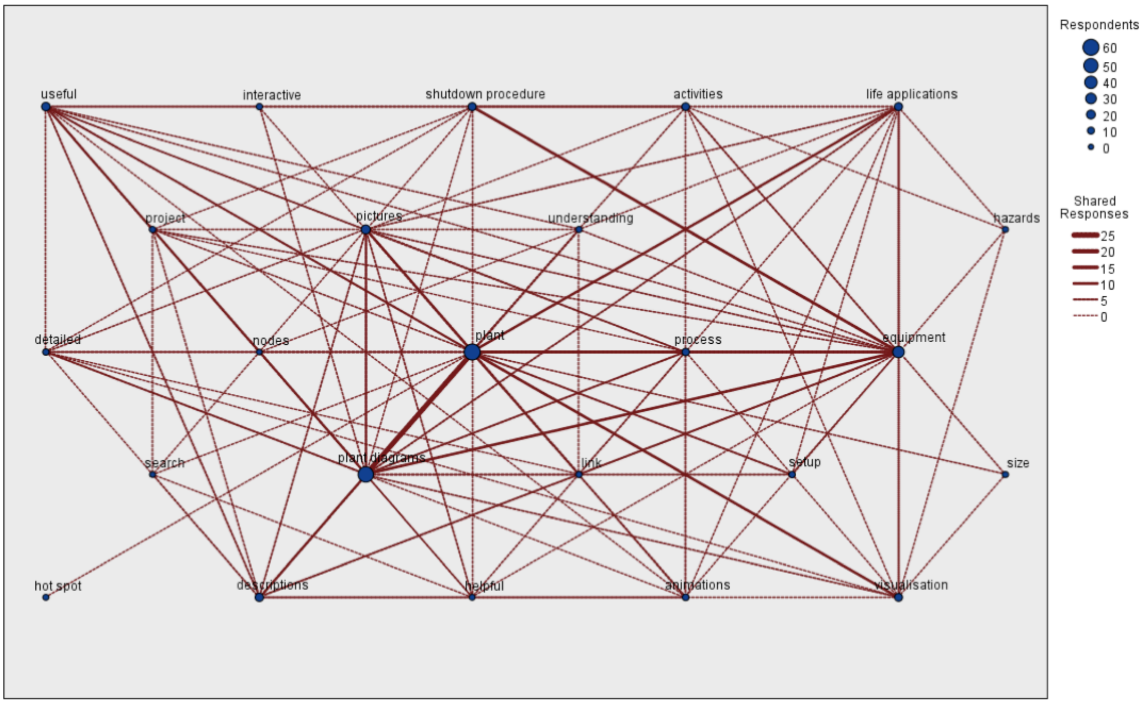

Figure 5. The category web for “What aspects of the VR system did you find more useful?”

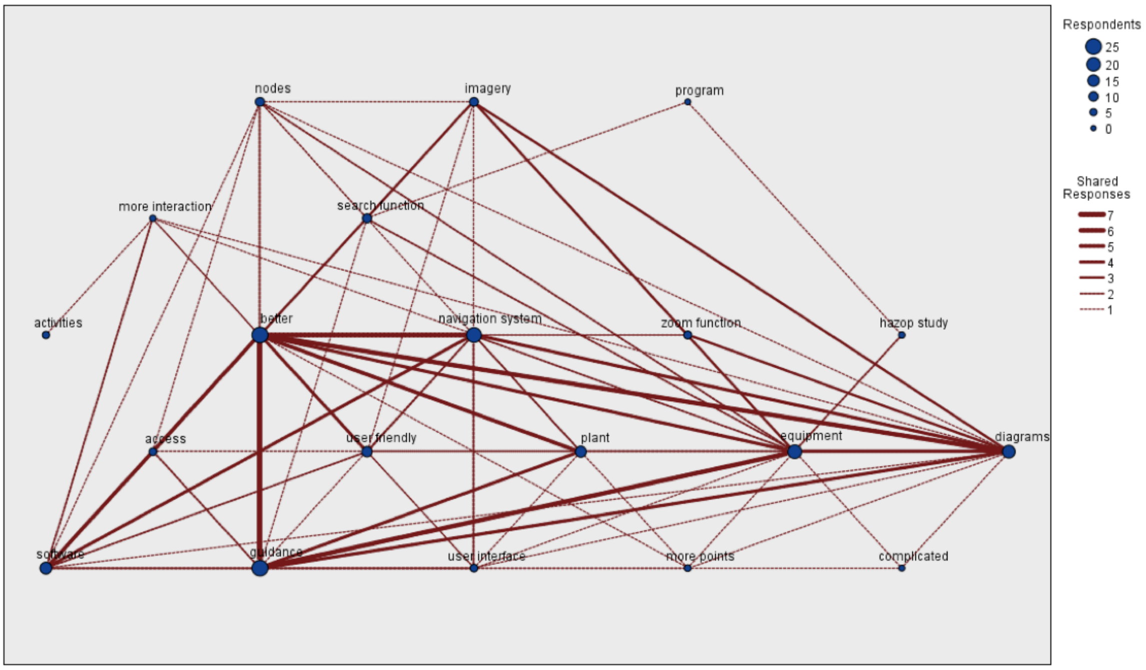

Figure 6. The category web for “What aspects of the VR system need improvement?”

With regards to the aspects that the students found most useful, “plant diagrams” and “equipment” featured strongly in the category web, followed by “life applications”, “visualisation” and “pictures”. From the questionnaires, students commented on the usefulness of the diagrams and the 3D photographs giving them the ability to view a real industrial plant. This is understood to show that the VR plant can enhance an engineering student’s understanding of industrial sites prior to entering industry, thereby making the student more industrially-aware upon graduation. Comments related to "the aspects requiring improvement" question were dominated by "navigation system", "guidance", "software", "diagrams" and "equipment". Difficulty navigating through the program has already been identified as an area for improvement and this relates to the request for guidance also. Regarding the equipment, many responses from students discussed the lack of flexibility in viewing particular pieces of equipment at the nodes and recommended including more information about the equipment, such as size information and a more detailed process explanation.

CONCLUSIONS

Two core chemical engineering units, Process Heat Transfer and Risk Management, were chosen to incorporate a virtual reality environment into the engineering coursework. This was done to set up a study to ascertain the value of the software as a learning tool and to determine whether the students perceived its use as beneficial in increasing their understanding of the concepts covered in class.

From the research conducted, the VR software was validated as engaging and enjoyable for students. Although actual effectiveness as a learning tool was only assessed by using one pre/post test, the perceived usefulness of the program in enhancing students' understanding of engineering concepts was found to be very positive. From the students' responses and suggestions, areas for improvement were identified and are in the process of being introduced into the environments. The authors intend to further evaluate this learning environment after incorporating the suggestions made.

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Biographical Information

Associate Professor David Shallcross is Head of the Department of Chemical and Biomolecular Engineering and Associate Dean (Teaching) for the School of Engineering. He is the Founding Editor of the international peer-reviewed journal *Education for Chemical Engineers.* David has won national and international awards in recognition of his leadership in chemical engineering education.

Professor Ian Cameron is a professor of chemical engineering at The University of Queensland and an ALTC Senior Fellow and Discipline Scholar, known internationally for his leadership in process systems engineering and risk management research and education. He was the AAUT 2003 Prime Minister's Teacher of the Year award winner.

Professor Caroline Crosthwaite is Director of Studies of the Faculty of Engineering, Physical Sciences and Architecture at the University of Queensland. She was instrumental in the design and introduction of the new project-centred learning in Engineering at UQ.

Professor Moses Tadé is the Dean of the Curtin Engineering School. He is well known internationally for his contributions in the areas of biochemical engineering, as well as process modeling, simulation, optimization and control. His expertise in process engineering provided a significant contribution to this project.

Dr Nicoleta Maynard, is a lecturer in chemical engineering at Curtin University. She won the Early Career Award for Excellence and Innovation on Teaching at Curtin University and the Australasian Association for Engineering Education Awards (AAEE) and Engineers Australia Citation Award 2009 for "demonstrating a broadly based high quality approach to teaching, curriculum development and educational research".

Dr Gordon Ingram, is a lecturer in chemical engineering at Curtin University. He plays a key role in implementing the VR project into the Chemical Engineering Curriculum.

Ms Jacinta Kingdon is a Curtin Engineering 2011 graduate, currently working with WorleyParsons.

Dr John Kavanagh, is a lecturer in chemical engineering at the University of Sydney. John was a member of both ALTC grants. He has been a key player in deploying the original immersive VR learning environment into the classroom.

Associate Professor Roger Hadgraft, The University of Melbourne, is a civil engineer with more than 15 years involvement in improving engineering education. He has published many papers in the area, with a particular focus on problem/project-based learning and the use of online technology to support active learning.

Ms Jo Dalvean is the Multimedia Project Manager for VR Learning Environments. She has a background in online application and web development.

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