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PE4005 RESEARCH PROJECT

The Application & Assessment of Dynamic Operations Simulation in Process & Chemical Engineering Education & in Industry

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Summary

Plant operations directly influence the safety, productivity, profitability, stability and controllability of a process. Substantial financial losses are still endured in Process and Chemical industries worldwide, a significant proportion of which come as a result of human error when faced with avoidable process upsets. There is a need for the continuous development of employee competence in the ever-increasing number of complex processes in industry. Dynamic Operations Simulation (DOS) has been proven to effectively improve plant operations knowledge and understanding in the processing industry workforce. DOS is primarily used as a training tool for Operations staff in industry. This research explores the application of DOS for Process and Chemical Engineers as they too have direct impact on plant operations. Simulators as a learning tool can be used to provide a fertile learning environment for students. One particular avenue that is explored in this report is the integration of DOS into Process and Chemical Engineering education and its potential to harvest more operationally aware Engineers for the future.

Extensive research into current applications and opportunities of DOS as well as survey feedback from current users of DOS formed a state of the art review. A bespoke DOS exercise was developed and demonstrated in the form of interactive workshops to students of Process and Chemical Engineering (PCE) in UCC and also to recent graduates of the degree currently working in industry to evaluate the suitability of DOS as a learning and training tool for Process and Chemical Engineers.

Users of DOS in industry approved of DOS as a means of gaining confidence with troubleshooting and operating more efficiently on plant. The graduate engineers strongly agreed that DOS would be just as beneficial for Process and Chemical Engineers as it would improve communication between engineering and operations. PCE students responded positively to DOS, stating that a visual hands-on learning tool can help to apply theoretical learning to real-life situations. Process Design and Process Dynamics & Control were concluded as modules that would benefit most from DOS. A case study established an opportunity for DOS to enhance the final year Design Project in UCC. It was concluded that DOS should indeed be used as a training tool for Process Engineers in industry and integrated into PCE education as a learning tool.

Acknowledgments

First and foremost, I would like to acknowledge the help provided by my academic mentor for this research project, Dr. Denis Ring (University College Cork), for his continual advice and encouragement which allowed for satisfactory progress to be made over the course of the project. On this note, I would also like to thank the module coordinator, Dr. Maria de Sousa Gallagher (University College Cork), for the guidance that she offered over the course of the project.

I would also like to thank Mr. Matthew Garvey (Simulation Solutions Inc.) for supplying me with the software needed to gain an understanding of Dynamics Operations Simulation, without which I would not have been able to carry out workshops that were essential to my research. His availability and expertise in the matter was a valuable resource.

Finally, I would like to thank those who participated in workshops and completed surveys that were critical to my research.

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1. Introduction

1.1 Background

Plant safety and process optimisation is high on the agenda at many companies. Hence, the industry has seen advancements in process technology to promote safety and optimisation for the ever-increasing number of complex processes in industry (Khani & Koivo, 1998). However, substantial losses are still being seen in the industry worldwide due to employee errors, which is essentially the failure to respond rapidly and appropriately to changing plant conditions. It is estimated that in the U.S. alone, $20 billion is lost annually in the process industry from accidents, $10 billion of which is directly attributable to human error (*fig. 1*) (Walker, Cammy, Ellis, & Seibert, 2011).

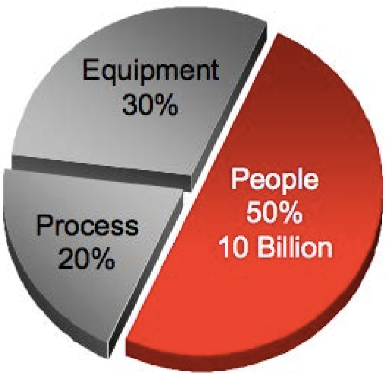


Figure 1 Breakdown of Causes of Error and Losses in the Processing industry in the US

These alarming figures indicate the need to develop more effective methods for training staff in the processing industry rather than the traditional 'on-the-job' mentoring or classroom training approach (Walker, Cammy, Ellis, & Seibert, 2011). According to the Organisation for Economic Co-operation and Development report: "Good (process) design should be complemented by proper safety management systems, including: training, retraining, and education of employees. […] When employees are well-trained, they can be expected to react appropriately in abnormal and unexpected situations, especially when they have some time to recover" (OECD, 2003).

Developments in technology have facilitated a new generation of powerful training tools. One such technology is *Process Simulation.* It provides "idealistic" representation of industrial processes by means of the application of mathematics and first principles i.e. conservation laws, thermodynamics, reaction kinetics etc. However, it does not consider the inherent dynamic behaviour of processes. *Dynamic Process Simulation* models have since been established to take into account the mass and energy rate of accumulation within a system (da Silva, 2015) (*fig. 2*). *Dynamic Operations Simulation* (DOS) is a tool that uses dynamic simulation models to simulate operations on a virtual plant. Much like flight simulation is used in aviation as a powerful training device and can be more effective than training in an aircraft (RoyalAeronauticalSociety, 2009), DOS can provide complete replication of the control room and allow users to practice and master their response to high risk situations without endangering the plant or personnel (Siminovich & Joao, 2013). Although Process and Chemical Engineers are a critical factor in plant operations, this key training methodology is used primarily for Operations staff only.

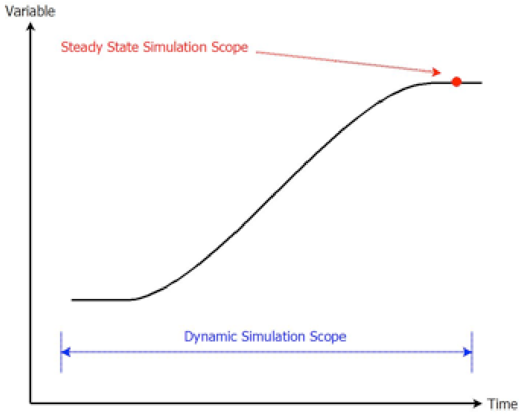


Figure 2 Comparison of Steady State and Dynamic model Scopes

This prompts the potential opportunity that DOS may have for Process and Chemical Engineers. Allowing Process Engineers to experience plant operations has the promising means to improve their overall skills and performance and increase operational awareness, skills and readiness (Schneider Electric, 2017). This in turn creates a more efficient process in terms of trouble shooting, analysing and ultimately reducing losses and accidents.

It could be argued that this type of training, like flight simulation for pilots, is vital for graduate Process and Chemical Engineers to gain hands-on experience before taking off into the working world. Through exposure to DOS in their graduate program training, it is probable that graduates would gain a higher level of competence and plant understanding that could benefit companies who constantly hire new process engineers with limited plant experience. (Careers Portal, 2017).

DOS relevance to Process and Chemical Engineers can be expanded even further. Many PCE courses do not reflect current practices in the chemical process industries (Alford & Edgar, 2017). There is potential to integrate DOS into PCE education as a learning tool to harvest operationally aware and ready Engineers since Dynamic Simulation is the link between training and education and design, safety and operations (*fig. 3*).

Figure 3 Dynamic Simulation as a link between Safety, Design, Operations and Education

1.2 Rational

The rationale for carrying out this research project is to assess DOS as a resource for Process and Chemical engineers and also as a tool for PCE education.

The capabilities of DOS in industry and how it can contribute to influencing plant safety and performance of operations will be evaluated.

The relevance of students at 3rd level getting exposure to DOS and how it can be integrated in today's curriculum as an effective solution to contribute to the Process and Chemical engineer's skill set will be investigated.

1.3 Objectives

The overall objective for this research is to create an in-depth understanding of the impact DOS has as a training tool in industry and the opportunity DOS faces as a learning tool in 3rd level education. The project is set out with the following intentions:

- Develop a **state of the art review** to gain a full understanding of the background and work already carried out in the field
- Gather and analyse survey feedback from users of DOS in **industry**
- Investigate the application of DOS for PCE **graduates** by demonstrating a bespoke DOS exercise to graduates
- Assess the impact of DOS as a learning tool in the PCE **education** by giving a DOS workshop and survey to PCE students
- Develop a **case study** for DOS evaluating an opportunity within the PCE curriculum
- Make **conclusions** based on this feedback regarding the relevance of introducing DOS to a modern PCE curriculum and at industry level

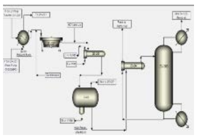
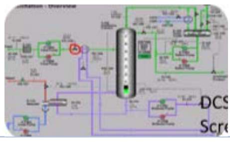
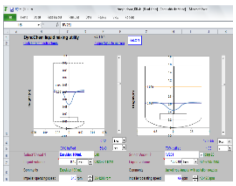
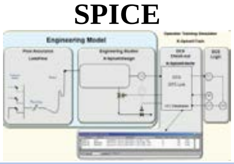
Based on these findings, certain recommendations will be made regarding future developments and applications of DOS for graduate and undergraduate Process and Chemical Engineers.

2. State of the Art Review

2.1 DOS Today

Process simulation has been a key tool of design and control since the early 1960's (Motard & Shacham, 1975). Since then, process simulation has indeed evolved, with research and development concentrating on the areas of dynamic process simulation. Currently, there are countless dynamic process simulator packages available for industry and universities. They are available for different industries, purposes, scales and under different commercial conditions (*Table 1*) (Simulate Live, 2017).

Table 1 List of Dynamic Process Simulators

Dynamic Process Simulator Package	**Features**
Aspen Plus 	✓ Wide range of calculations for design, operation, & optimization ✓ Steady-state & dynamic simulation of petrochemical, chemical and pharmaceutical processes ✓ Mixed solution methodologies to achieve fast calculation & provide full specification flexibility ✓ Scale from single models to full facility flowsheets.
Simulations Solutions 	✓ Wide variety of high fidelity Process Simulators which include both a DCS component and a Virtual Reality Outside Operator ✓ Hands on training simulators for specific start-ups, shutdowns, emergency response, control system operability, hazardous analysis of key units and procedures validation.
Simtronics 	✓ Offers Operator Training Simulator using Standard Process Models with Virtual Field Operator and Dynamic Training Aids ✓ Process Plant troubleshooting ✓ Effective Console Operations ✓ Abnormal Situation Management ✓ Process control and optimisation
DynoChem 	✓ Process development & scale-up software for pharmaceutical industry used in Big Pharma for over a decade ✓ R&D sites and Primary Manufacturing facilities ✓ On-site training, technical user support on projects, regional user group meetings & targeted application webinars. ✓ Tools provided for companies to develop their own template models, implement multi-site equipment databases and also train in-house experts
SPICE 	✓ Detailed simulation of oil and gas processes and control systems ✓ Combines system management, thermodynamics, and numerical solvers with flexible and intuitive graphical user interface ✓ Operator Training Simulator with real process conditions

Today, processing industries make significant use of Dynamic Process Simulation. Universities are incorporating the use of process simulators in design courses. However, extensive research into DOS has concluded that the use of simulation and its potential benefits needs to be improved (Yang, Yang, & He, 2001). Research states that dynamic simulation may be fundamental in reducing the impact of accidents or even in preventing them (Dipesh S. Patle, 2014). DOS is an extension of Dynamic Process Simulation. It generally includes both a DCS (Distributed Control System) component and a 3D Virtual Reality element known as an Outside Operator, which is fully integrated with the DCS (*fig. 4*). One can operate all pieces of equipment that are represented on the DCS using this Outside Operator feature – such as 'manual' opening or closing of valves – and these actions are reflected in real-time on the DCS schematics, and vice versa. There is an extra level of operator/process engagement that can acquaint the user with the geometric properties of processes as well as the operation and kinetics associated with it.

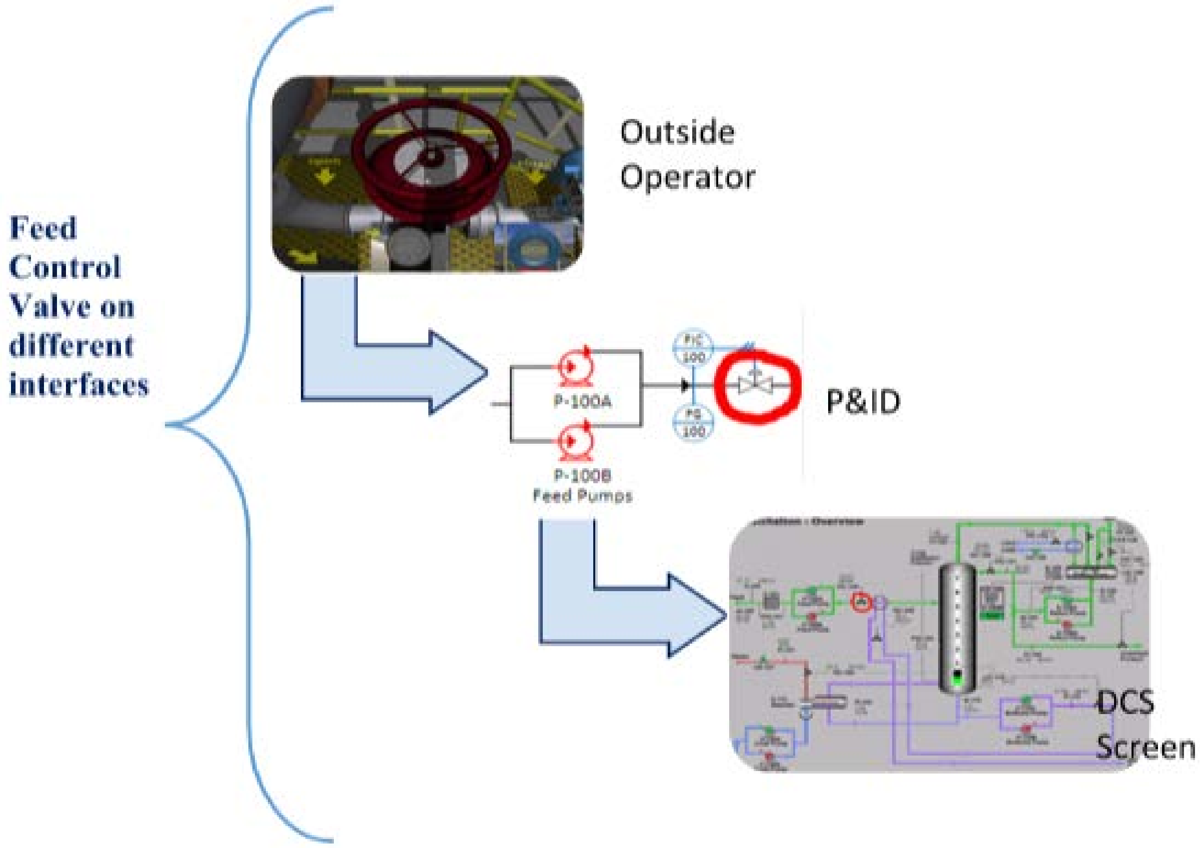


Figure 4 Outside Operator, P&ID and DCS elements to DOS

2.2 DOS AS A TRAINING TOOL

Today, DOS as a training tool comes in the form of Operator Training Simulators (OTS) that have been used for more than 20 years in the oil and gas industry (McArdle, Cameron, & Meyer, 2010). As the name suggests, these high fidelity training simulators are used primarily for Operations staff training.

An OTS replicates process dynamic behaviour over a wide range of operations including start-up, shutdown, and critical situations. The components of a typical DOS should include:

- Same equipment, DCS configuration, tags and logic as the actual plant,
- Training environment almost identical to the control room,
- High level of realism due to accurate dynamic process models,
- Realistic process models to provide the sense for urgency in reacting to training exercise events, used in teaching operators to recognize and react to plant-specific events and scenarios, with an instructor console,
- The ability to run exercises without an instructor
- Non-real-time simulation to allow the user to experience the operation in a fraction of the time

There have been many case studies that have proven the benefits of DOS training. A Nexen Inc. oil-sands upgrading plant in Alberta, Canada simulated a complex process plant control system prior to start-up using DOS technology supplied by SimSci-Esscor (Iversen, 2009). Each console operator underwent 160 hours on the simulator during the initial four-month training period, and an additional 40 hours per year in OTS refresher training.

The simulation training specialist stated that by using an OTS system, it was possible to take an operator who has no control room operations experience and have him sitting, by himself, on the panel, within four months. The OTS was a major factor in quickly bringing the operators up to speed resulting in a faster, smoother and problem-free plant start-up. The company credits OTS for eliminating any issues related to the start-up of new complex units noting no fires or any operator errors.

OTS benefits also extend well beyond plant start-ups to help keep plants running smoothly and more productively once they are up. A strong OTS program helps to eliminate errors that can lead to accidents, product loss or costly plant shutdowns. Continuing refresher training can help keep Operations staff skills up to date for infrequently performed tasks such as start-ups and shutdowns, and also prepare them for the unexpected.

A senior analyst at ARC Advisory Group Inc., in Dedham, Massachusetts stated that manufacturing users must look beyond just the training aspects of the technology, believing that the OTS should be an integral part of an operating facility, not just to train, but to do 'what-if' scenarios, troubleshooting, engineering studies and continuous improvement (Iversen, 2009).

Honeywell International Inc. reported that there were concerns that training practices in industrial process control environments are ubiquitous among plant personnel. (Bullemer & Nimmo, 1996). It was found that there was emphasis on informal "on-the-job" training. Strong initial training for field operators, moderate training for console operators, and weak training for all other operations personnel. Due to the aging workforce and the influx of inexperienced Process and Chemical Engineers, there is an argument that DOS training is not only vital for Operations staff, but also for Process and Chemical Engineers.

2.3 Future of DOS

Advancements in virtual reality technology are providing new opportunities for improved Operations staff training and machine design within various industries (Jensen, 2017). The dynamic simulation of a real-world environment or situation provides an artificial experience which makes the user feel as if he or she is actually in the simulated environment (*fig. 5*).

3D virtual reality DOS has the potential to improve cognitive readiness by addressing the three components of situation awareness:

- "experiencing" the plant and its units,
- comprehending their meaning and purpose
- learning how to project the current status in the near future

Figure 5 Virtual Reality Training

Invensys Operations Management's EyeSim system created a computer-generated, photorealistic 3D representation of a real or proposed plant which is integrated with the plant's OTS dynamic model. This enables trainees wearing stereoscopic headsets, or goggles, to enter a completely immersive environment in which they can move freely throughout the virtual plant, seeing exactly what they would see in a real plant (Iversen, 2009). Users get familiar with the different plant sections, as well as individual process units compared to traditional training systems. Modern 3D animation and other tools promote communication and understanding across a wide audience. Using a game pad, they can interact with objects in the plant environment, opening and closing valves, for example. Trainees also hear appropriate sounds around them as equipment turns on and off. The experience has a video game-like feel that is certain to seem familiar to many new recruits and younger employees.

2.4 DOS in PCE Education

Research concludes that people learn better by experience than through reading or lectures (*fig. 6*) (Dale, 1969). People learn best when they use perceptual learning styles. The more sensory channels possible in interacting with a resource, the better chance that many students can learn from it. Instructors should design instructional activities that build upon more real-life experiences.

Simulations can be used to provide an active, fertile learning environment for students (Educational Simulations, 2011). The use of simulated activities in education is widely becoming recognised as an important tool in schools. Activities that promote learning tend to simulate an activity that is "real", and so it can be said that they are "virtually real" so that there is little difference between the simulated environment and the real one. "Hands-on" learning involves students so that they become participants, not mere listeners or observers. Students learn

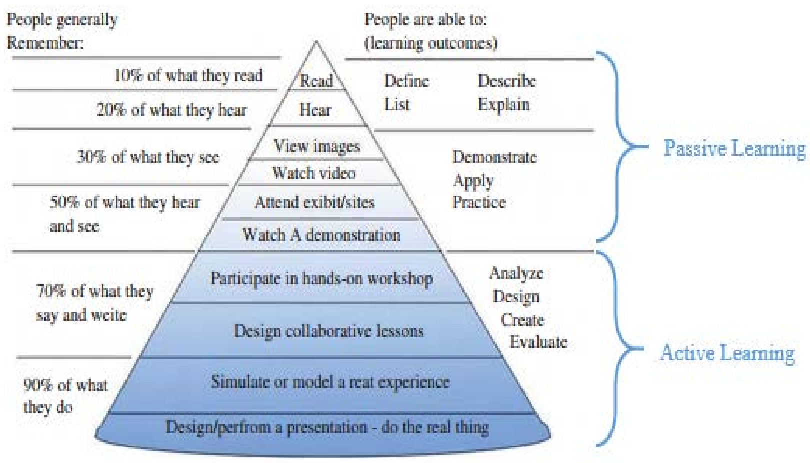


Figure 6 Edgar Dales Cone of Experience

better from their own experiences than having others' experiences related to them. This also allows the students to take on responsible roles, find ways to succeed, and develop problem solving tools as a result of the interaction.

A study performed by Purdue University, Indiana, about the effects of "hands-on" active learning in the engineering and technology sectors revealed that the students who were involved in a "hands-on" project learned more and demonstrated a deeper understanding of the issues than the traditional group (Risowski, Todd, Wee, Dark, & Harbor, 2008).

Process simulators are basic tools in PCE programs (Dahm, Hesketh, & Savelski, 2002). Senior level design projects typically involve the use of commercial or academic simulators (e.g. ASPENPLUS, ChemCAD) for performing mass balances, generating flowsheets etc. (*see Table 1*). While engineering programs do an excellent job in providing students with the technical skills needed for them to become Engineers, it is done within an academic context (Rhinehart, 2015). As a result, students do not graduate with the perspectives and expectations to be successful in the disparate context of industrial practice. Although graduates enter industry with fundamental skills, their perspectives are academic. They are aligned with learning, not doing; with perfection, not sufficiency; with knowledge, not fruition. There is a misalignment between knowledge, skills and attributes desired by employers hiring engineering graduates and the skills which engineers possess upon graduation. Clearly, there is a strong need to bridge the gap between theory and application within education.

The use of DOS as a learning tool in education gives students an opportunity to apply knowledge and practice skills learned in the classroom. The "hands-on" experience provided by training simulators gives participants an added level of confidence, security and knowledge to function competently when they start out at work (Walker, Cammy, Ellis, & Seibert, 2011).

In order to successfully integrate DOS as a learning tool in education, there is a need to have the proper resources to teach it. The teaching of hands-on simulation in a big class is a challenging task due to students of different levels of understanding and learning speed (Foo & Chong, 2017). It is recommended to maintain the ratio of students to instructors to max

30:1 to ensure good interactions. Extra efforts are also needed in order to make good learning material for the class.

A blended classroom approach teaching style which is a mix of traditional face-to-face teaching and technology-based learning. There has been a lot of evidence on successful blended classroom teaching experience from universities.

A DOS model of a binary distillation column using D-SPICE (*see table 1*) software was integrated into a basic Chemical Engineering module for 1st year PCE students in Oslo University College (Komulainen, Enemark-Rasmussen, Sin, Fletcher, & Cameron, 2012). The learning goals of the distillation simulation exercises included:

- Ability to use the software for simple case scenarios,
- Insight into the dynamic operation of a distillation column and how the changes in the manipulated variables affects the controlled variables, and
- Ability optimise the distillation sequence, i.e. the values of the manipulated variables that would give highest yield in the distillate.

The 2 hour simulation sessions were led by the teacher for groups of 8 students who were encouraged to work in teams of two in order to support each other and to engage into discussion about the results. The students were running the distillation model, changing the manipulated variables and observing the simulated process behaviour on the software.

The teacher reported very positive learning environment, the students were fast to adapt to use the simulation tool and group size up to 10 students was manageable due to successful team work. These small group sizes aren’t always feasible for bigger universities. Larger student to teacher ratios may act as a disadvantage for successful integration.

Half of the students considered the software easy to use and were comfortable using the tool alone. 90% of the students that liked using D-SPICE, stated that utilization was a good idea and recommended it as a suitable tool for the PCE course. Most of the students agreed that simulation enhances understanding of theory and makes learning more interesting. “Simulation enhanced my learning” was agreed by 95% of the students.

The learning outcome of the DOS exercise was measured by a mid-term multiple choice exam and a formal final exam. The average result of the mid-term exam was 77%, and the average result of simulation question in the final exam was 62%. Compared to the average of the whole exam 56%, performance with simulation tasks was better compared to the traditional calculation tasks. This proves that the use of DOS as part of a module strengthens students' grasp on basic engineering knowledge.

Process control at Aston University is taught with the use of D-SPICE DOS software for 2nd year PCE students (Komulainen, Enemark-Rasmussen, Sin, Fletcher, & Cameron, 2012). It contributes to the formal goal of understanding of the operation of a process control loop with different types of control strategies. Learning outcomes include:

- On/off and modulated feedback control,
- Different forms of cascade and feed-forward control,
- Advanced control focusing on control systems design as part of wider design studies.

Dynamic simulation is used as a teaching tool in two ways in the curriculum: it is introduced into classroom teaching where the tutor uses it to demonstrate features of controller behaviour, and it is used in tutorials where each student can run the program and explore the models.

The principles of the process model used were familiar to the course participants as they already completed a project which involves construction and operation of a similar process. This is an example of how dynamic simulation software can build upon existing process knowledge.

3rd and 4th year students' attitude towards the use of dynamic simulation as a training tool has yet to be formally assessed within Aston, even though it is a valid factor in the integration of the software into education. However, high test results show a good understanding of the tasks. Students take to the simulation tool very well and use of it leads to a lot of conversations with the students about their understanding of process control.

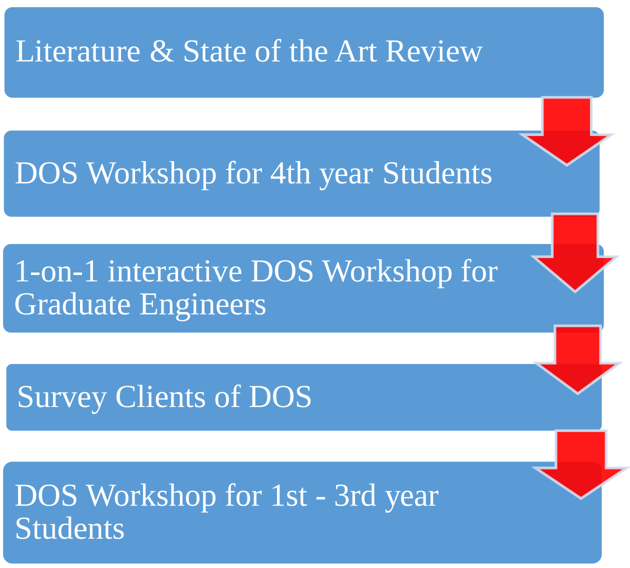
These studies performed at Oslo University College and Aston University confirm that DOS can be successfully integrated into undergraduate teaching as a learning tool.

Engineering education is incomplete without laboratory practice. Laboratory experimentation not only improves students' understanding of theory but also promotes development of soft skills, such as team work and problem solving (Martinez-Jimenez, Pontes-Pedrajas, & Polo, 2003). The main advantage of virtual labs is that students can run simulations independently, whereas many of the commercial simulators lack interactive capabilities and must be used in a specific location, i.e. at the university. DOS could provide a wide range of unit operations for students to immerse themselves in within a safe environment in their own time.

3. Materials & Methodology

Following extensive research into Dynamic Operations Simulation and assessing its current applications and capabilities at both an educational and industrial level, an evaluation of DOS from students, graduates and professionals was essential for further analysis on the topic.

Simulation Solutions Inc. DOS software was used to create bespoke interactive DOS workshops for PCE students in University College Cork and for a 1-on-1 DOS session with a PCE graduate engineer working in the biopharmaceutical industry. Following the workshops, the participants were asked to complete surveys that aimed to assess the suitability of DOS in education and in industry. Surveys from clients of DOS were gathered and used along with results from student surveys to make recommendations for use of DOS as a training and learning tool for Process and Chemical Engineers.



3.1 Simulation Solutions Inc.

To attain the full potential of DOS as a learning and training tool, it is essential that an appropriate DOS package is selected. Simulation Solutions Inc., USA produce high fidelity training simulator systems for Operations staff, Engineers and Technicians. Clients of the software include Du Pont, Exxon, Foster Wheeler, Kellogg, Phillips, Stone and Webster, STRATCO and others. The company has also extended their reach to universities such as Columbia University and New Mexico State University, along with 33 other colleges, to teach students how to operate, start-up/shutdown and troubleshoot units with common faults found in industry (Simulations Solutions, Inc., 2018).

Over 40 standard process models are available for non-site-specific training purposes, serving as the first building blocks of Operations training (*fig. 7*). When advanced training is required, custom process models that replicate realistic, high fidelity dynamic process models are used.

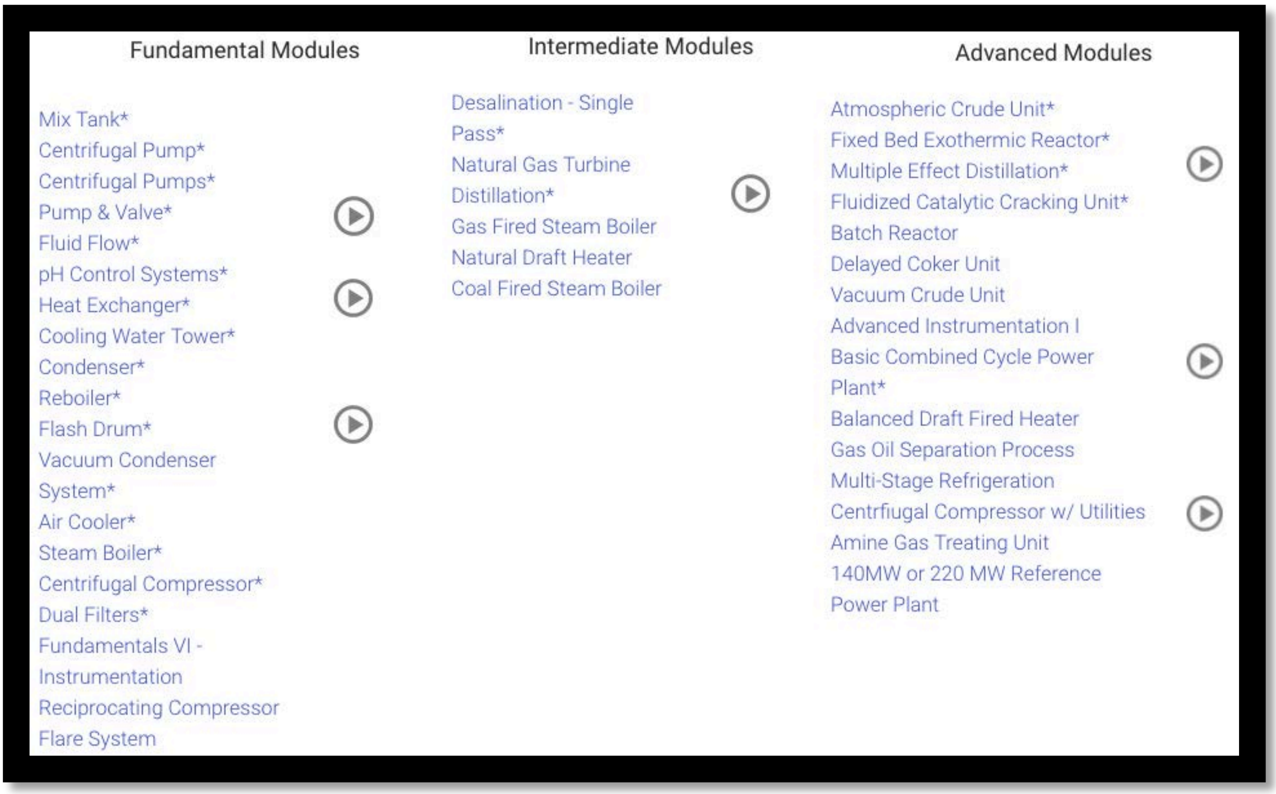


Figure 7 Simulation Solutions Inc. list of Process Simulator Modules

The DOS software includes both a Distributed Control System (DCS) component and a VR element known as an Outside Operator. Users can operate and control valves, pumps, towers, and reactors and observe dynamically over a full range of operating conditions how equipment, feedstock, catalysts, and products respond to changing feed rates, temperatures, pressures, etc. All Outside Operator station functions and responses are driven by differential equations and mathematical models.

3.2 DOS Training & Exercises

Simulation Solutions Inc. believes the implementation of a Training Simulator is just as important as the software itself and offers a two-day training course to clients. Using an innovative approach to both Classroom and Simulator Exercises, the courses focus on improving safety, knowledge, competency and hands-on skills in Operating and Troubleshooting.

Each course focuses on fundamental, yet comprehensive, individual and team exercises which promote trainee-driven learning. These exercises use a Minds-On/Hands-On Training Strategy (*fig. 8*). Students work through 5 major phases:

- Identification
- Normal Operations,
- Start-up & Shutdown,
- Troubleshooting, and
- Optimization.

Or, 'INSTO'.

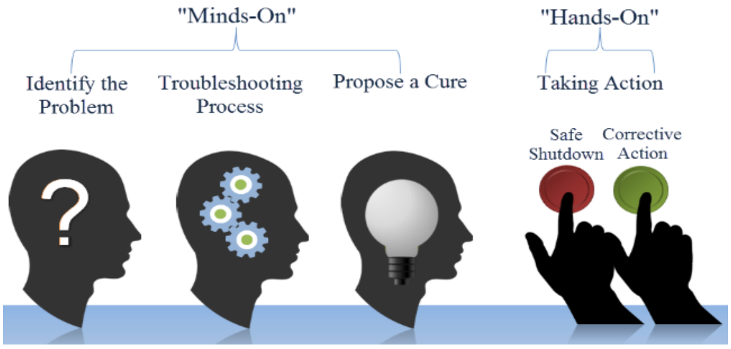


Figure 8 Minds on Hands on methodology

The exercises developed by Simulations Solutions Inc. that comply with their INSTO methodology are summarized in *Table 2*. Highlighted in blue are the exercises implemented for DOS workshops for this particular research. Each trainee is provided with their own Simulator modules and exercise booklet for each module for the duration of the course. To encourage group discussion and an active learning environment, trainees shared their answers on a flip chart in front of the class.

Table 2 DOS Exercises developed by Simulations Solutions Inc.

Identification	**Normal Operations**	**Startup & Shutdown**	**Troubleshooting**	**Optimization**
Process Description	What-If	Scrambles	Trend Match	Optimization
Control Philosophy	Error Identification	Procedures	Troubleshooting A Cause & Effect	
Process Safety and P&ID Review			Troubleshooting A Cause & Effect Match	
Outside Operator Identification			Troubleshooting B	
DCS Identification			Troubleshooting C	
DCS-P&ID Matching				
Reading and Round Sheet Introduction				

Identification

The introductory exercises teach trainees how to quickly familiarise themselves in a new plant, figure out what is there and how it is connected using P&IDs, the plant itself, and the controls.

Process Description: a brief explanation of the process schematics is given by the instructor. The function of the unit operation, the overall energy and mass balance of the system, control strategies, alarms, design specifications, etc. are described.

Outside Operator Identification: The 3D virtual plant is introduced through an exercise in which the instructor guides the trainees through the 3D plant asking them to identify and locate an instrument/piece of equipment on the DCS. This familiarises the trainee with the outside operator feature, which is an essential feature to train staff in correct handling and identification of unit operations and visualising emergencies.

DCS and P&ID matching: Trainees are asked to match the equipment and controls on DCS (Appendix F) screens to the P&ID (Appendix G). This simple exercise is a quick hands-on method of understanding the DCS graphic and how it relates it to the P&ID.

Normal Operations

The objective of these exercises is to help the trainees understand how the plant runs under normal conditions and learn/develop a sense of "expected results" when making operational moves on a plant.

What-if: Trainees are given a typical plant upset or failure and are asked to predict how this will affect certain variables within the plant: process variables, controller outputs, alarms, equipment, safety etc. Trainees are encouraged to work as a group to predict the outcomes and write them on a flipchart. After the trainees the predictions are recorded, the upset or failure is introduced into the simulator and the responses are observed. This trainee-led exercise helps to develop a deeper understanding of plant operations and also begins to develop trainee problem solving skills with respect to recognising and identifying effects.

<u>Start-up and Shutdown</u>

This exercise is given with the objective that trainees can follow and perform procedures or start-up and shutdown. The initial exercise starts by giving the trainee a sense of the proper order and important safety issues that comes with emergency start-up and shutdowns.

Scramble: Trainees are given steps of a start-up procedure in a scrambled order. In groups, they are asked to re-arrange the steps in an order that will start up the process safely and efficiently. Trainees can then implement the procedure on the DOS to test their order.

<u>Troubleshooting</u>

Trainees learn to approach plant problems/upsets and troubleshoot them in a systematic way through these exercises and implement their solutions on the DOS.

Cause and Effect Match: A plant upset or failure is pre-programmed onto the DOS by the instructor. It is up to the trainee to solve and recover from the unknown upset keeping in mind both safety and operational concerns.

<u>Optimisation</u>

Trainees learn the safe limits of operation given the current set of equipment, controls, feedstock, etc. in order to maximize productivity/profits. They are tasked with carrying out the correct methodology on the DOS given an objective from supervisor e.g. increase feed while maintaining composition of overhead and bottoms products within a certain design specification. This type of trouble shooting with optimisation replicates what Process and Chemical Engineers are generally tasked with.

3.3 DOS Workshops

3.3.1 4th Year Students

Length: 2 hours

Size: 20 students, 1 instructor

Module: Distillation Tower

Description: Each student provided with computer installed with Simulation Solutions software and supplied with Exercise booklet (*fig.9*).

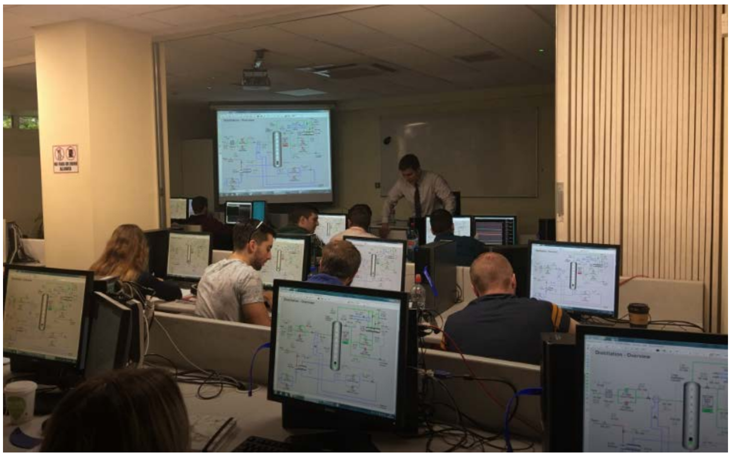


Figure 9 DOS Workshop for 4th Year PCE students, UCC

Introduction: Students were given an overview as to what DOS is, the role it plays in industry and its potential use at university level as a learning tool.

Identification: It was assumed that the basic schematics of the binary distillation column were known to final year PCE students, so a very brief overview of the tower was given on the DCS graphic, highlighting the mass and energy balances of the system and the controls in place. There was no DCS-P&ID matching exercise given as it was expected that students were aware of standard instrumentation symbols and graphics. The students were brought through the 3D virtual plant as an outside operator and tasked to locate and identify feed instrumentation, pumps, reboiler, overhead condensers and pressure controls.

Normal Operations: Students were asked to work in groups to fill out the 'What-If' exercise sheet (*fig.10*). The instructor called upon groups to give their answers and a reasoning behind their choice. To check their answers, students implemented the changes into the DOS and noted the changes. Students were encouraged to use the trend graphs feature to note changes in variables.

Variable / Event	Feed Flow FIC-100	Bottoms Level LIC-110	Bottoms Flow FI-110	Bottoms Temp TIC-100	Steam Flow FI-101	Bottoms Comp AI-110	Material	Energy
INCREASE 15% Feed Flow FIC-100	↑							
DECREASE 15% Feed Flow FIC-100	↓							
INCREASE 2.5% Bottoms Temp TIC-100				↑				
DECREASE 2.5% Bottoms Temp TIC-100				↓				
INCREASE 5% Overhead Pressure PIC-120								
DECREASE 5% Overhead Pressure PIC-120								
INCREASE 15% Reflux Flow FIC-121								
DECREASE 15% Reflux Flow FIC-121								

Figure 10 What if exercise for 4th year students

Start-up: One student at the top of the class was asked to rearrange the scrambled start up procedure (*fig. 11*) and justify the order of steps with the help of the class. The correct order was then explained by the instructor.

Troubleshooting: The students opened an exercise that contained an unknown process upset where Pump A failed after 2 minutes. They were tasked with going through the troubleshooting steps described by the instructor to solve the problem. They were encouraged to speak to each other and ask the instructor questions.

A. Establish vapor flow	G. Establish top Pressure control
B. Start reflux flow	H. Take off bottoms product
C. Start steam flow	I. Establish reflux drum level
D. Start feed flow	J. Take off top product
E. Start cooling water	K. Open vent valve
F. Establish a base level	
1. Start cooling water (E)	**#1 (E) MUST BE BEFORE #5 (C)**
2. Start feed flow (D)	
3. Establish a base level(F)	
4. Open vent valve (K)	**#4 (K) MUST BE BEFORE #7 (G)**
5. Start steam flow (C)	
6. Establish vapor flow (A)	
7. Establish top pressure control (G)	
8. Establish reflux drum level (I)	
9. Start reflux flow (B)	
10. Take off bottoms product (H)	
11. Take off top product (J)	

Figure 11 Start-up Scramble Exercise Sheet

3.3.2 1st – 3rd Year Students

Length: 40mins

Size: 31students

Module: Distillation Tower

Description: Classroom environment where students were supplied with exercise sheets with an instructor demonstrating DOS on projected screen (*fig. 12*)

Introduction: students were given an overview as to what DOS is, the role it plays in industry and its potential use at university level as a learning tool.

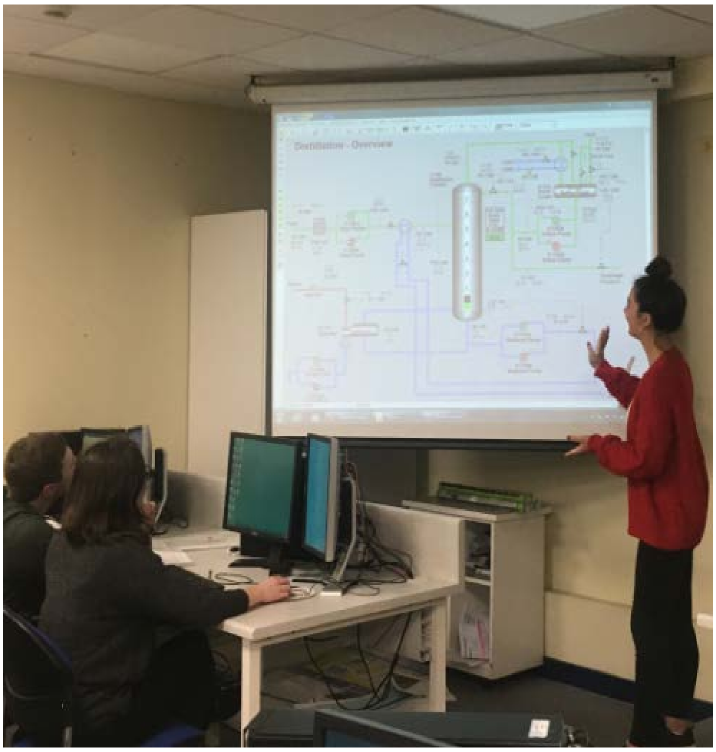


Figure 12 DOS demonstration for 1st-3rd year PCE students, UCC

Identification: The schematics of the binary distillation column designed to separate a pentane-hexane stream were described in detail as it was assumed this wasn't fully known to 1st-3rd year PCE students. The DCS-P&ID matching exercise (*fig. 13*) was given to familiarise the students with the control screen and P&ID drawing. The students were also brought through the 3D virtual plant as an outside operator and tasked to locate and identify feed instrumentation, pumps, reboiler, overhead condensers and pressure controls.

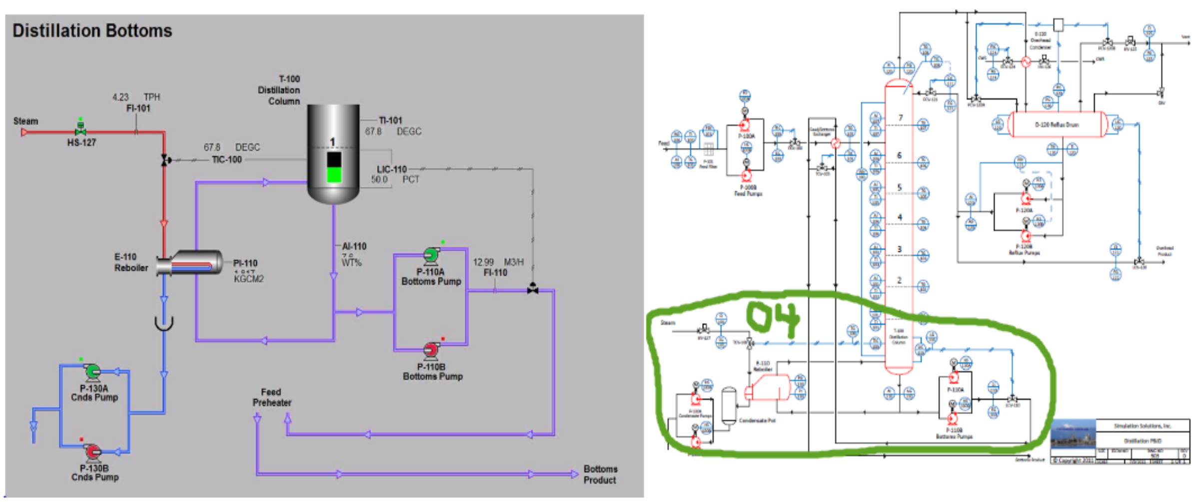


Figure 13 DCS-P&ID matching exercise

Normal Operations: Students were asked to fill out a simplified 'What-If' exercise sheet (*fig. 14*). The instructor called upon groups to give their answers and a reasoning behind their choice. To verify the answers, the instructor implemented the changes into the DOS and highlighted the variable changes by showing the students trend graphs. The students were encouraged to note where they went wrong and an explanation to the answers was given in detail.

	Feed Flow FIC-100	Bottoms Temp TIC-110	Overhead Pressure PIC-120	Reflux Flow FIC-121
INCREASE Feed Flow FIC-100				
DECREASE Bottoms Temp TIC-100				
INCREASE Overhead Pressure by 5% PIC-120				
DECREASE Reflux Flow FIC-121				

Figure 14 What if Exercise given to 1st-3rd Year students

Start-Up: No start up exercise was given to this group as it requires advanced operations knowledge therefore more time was needed. Instead, the instructor highlighted this feature of DOS as an opportunity for learning.

Troubleshooting: The instructor opened an exercise that contained an unknown process upset. Pump 100A failed after 2 minutes of running the simulation. The group were tasked with identifying the problem. Trend graphs and alarms were shown to the group. The group were then asked to come up with a solution to rectify the problem which was then implemented by the instructor.

3.3.3 Graduate Engineer

Length: 2 hours

Size: 1 trainee, 1 instructor

Module: Distillation Tower

Description: 1-on-1 DOS session. The trainee was provided with a computer installed with the simulation solution software and was given an exercise booklet (*fig.15*).

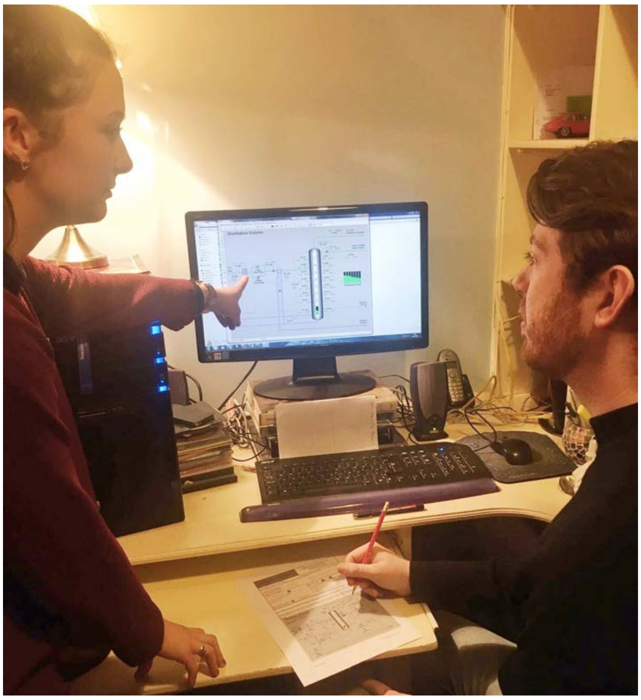


Figure 15 One on one DOS session with graduate Process Engineer

Identification: It was assumed that the basic schematics of the binary distillation column were known to the graduate engineer, so a very brief overview of the tower was given on the DCS graphic, highlighting the mass and energy balances of the system and the controls in place. There was no DCS-P&ID matching exercise given as it was expected that the trainee has experience of standard instrumentation symbols and DCS graphics as an Automation engineer. The trainee was brought through the 3D virtual plant as an outside operator and tasked to locate and identify feed instrumentation, pumps, re-boiler, overhead condensers and pressure controls to experience the plant.

Normal Operations: The trainee was asked to fill out the 'What-If' exercise sheet (*see fig.10*). The trainee was encouraged to talk thourgh their answers and give a reasoning behind their choice. To check their answers, the trainee implemented the changes into the DOS and noted the effects. The trainee was shown the trend graph function of DOS to compare answers.

Start-up: The trainee was asked to rearrange the scrambled start up procedure (*see fig. 11*) and justify the steps. The correct order was then explained by the instructor. There was not enough time for the trainee to perform a start-up procedure so this exercise was explained to the trainee as a potential training tool.

Troubleshooting: The trainee was tasked with running a bespoke Training Exercise that included specific instructions regarding plant operation/specifications over time. It was required to increase the composition of the overhead product by .2 WT% every 3 minutes for the next 12 minutes. The exercise contained built-in process upsets that were of an unknown nature to the trainee: Feed pump 100A failed after 4 minutes. The trainee was instructed to manipulate the composition of the overhead product while successfully troubleshooting any problems without any safety violations or quality issues. The instructor was on hand to guide the trainee through the simulation and answer any questions. The exercise sheet (*fig. 16*) was filled out by the trainee keeping in mind the key trouble shooting steps explained below.

OBSERVATIONS:
FIC-100 and FI-122 show no flow FI-120, FI-126, LIC-120, FI-101, PI-110, FI-110, LIC-110, AI-110 and AI-120 decrease TIC-105 increases

POTENTIAL CAUSES						
Equipment	Utilities	Instrumentation	People	Process Material	Environment	Down/Upstream
Feed Pump Failure	No Electricity flow to pumps	FIC-100 fails closed				Problem with upstream feed process

What are the safety concerns associated with the problem?		
Concern	Implications	Degree of Severity (1 = Not Severe, 5 = Very Severe)
Feed Heat Exchanger Damage	Potential for hydrogen cracking in exchanger shell	4-5
Off-Spec Products	Off-spec products may cause safety hazard for downstream processes	3-4
Pump cavitation	Pumps can be damaged if no liquid is flowing through them	3-4

Rank (1-3)	Probable Cause
1	Feed Pump Failure
2	No Electricity to Pumps
3	FIC-100 fails closed

3. CORRECT AND EXECUTE

Layout a plan to bring the system back to design conditions:

1. Place FIC-100 in manual control
2. Close valve output to about 20%
3. Start spare feed pump P-100B
4. Manually increase FIC-100 until flow is at design rate
5. Switch FIC-100 to automatic at design rate

Figure 16 Troubleshooting Exercise given to Graduate Engineer

The key troubleshooting steps are taught and implemented:

1. Identifying from alarms or otherwise that you have a problem,
2. Comparing the existing state of the unit to when the unit is operating normally,
3. Recalling what was learned from "Normal Operations" and using that knowledge and skill to separate "effects" from "cause(s)",
4. Correcting the problem safely and efficiently, including having to call for an emergency shut-down if that is what is required.
5. Tracking the process to determine if the corrections were proper and effective.

Surveys (Appendix C, D, E) were subsequently prepared for all the students who took part in the workshops to gain an insight into students' opinions on DOS as a learning tool for Process and Chemical Engineers in University and in industry.

4. RESULTS

4.1 PCE Student Survey Results

A survey containing 10 questions (*Table 3*) was sent to students who attended the workshops. Since there was a slight difference in both workshops (student interaction with DOS, length of workshop, level of initial Process engineering knowledge), the decision was made to create two separate surveys (*Table 4*). Where applicable, results were compiled together to form an overall PCE student opinion.

Table 3 Questions for PCE Students to gain insights into DOS

Insight	Question
Student awareness of DOS	Were You Aware of 3D Dynamic Operations Simulation prior to the Workshop?
Opportunities of DOS within Current PCE Modules	What areas of your degree are your most favourite, least favourite and requires modern development?
	In what area within the ciriciculum would DOS best suit?
	In what year of your degree would benefit from the use of DOS?
DOS and Hands-On Learning	From your course so far, how important do you consider hands-on learning in engineering education
	Do you think DOS could supplement/link theoretical material learned in class and practicle laboratory work?
Incorporating DOS into PCE curriculum	Was the DOS workshop of added value to your Chemical Engineering knowledge from 3rd level education?
	Should this type of (interactive) Dynamic Process Operations Simulation be incorporated into Chemical Engineering Degree courses?
DOS after 3rd Level	Do you think DOS would be of benefit in graduate engineering programs?

Table 4 PCE Student Survey Groups

Students	Group	# responses	Completion Rate
4th Year	**A**	20	100%
1st-3rd Year	**B**	31	100%

Within group B, 80.65% of the respondents were 1st year students, 9.68% were 2nd years and 9.68% were in their 3rd year. With such a large fraction of the group being 1st years, the feedback received by Group B is not a fair representation of 1st to 3rd year opinions on DOS. Therefore, Group B answers were further divided to isolate the different years where applicable.

4.1.1 Awareness of DOS

An initial question proposed to both student groups asked if they were aware of Dynamic 3D Operations Simulation software existing prior to the workshop. Almost two thirds of group A (4th year students) were aware of DOS, while the vast majority of group B (1st-3rd year students) were unaware of the software prior to the workshop (*fig. 17*). This contrast might suggest that 4th year students may have been exposed to 3D simulation during work placement, whereas the more inexperienced students have not seen 3D dynamic simulation in their curriculum so far.

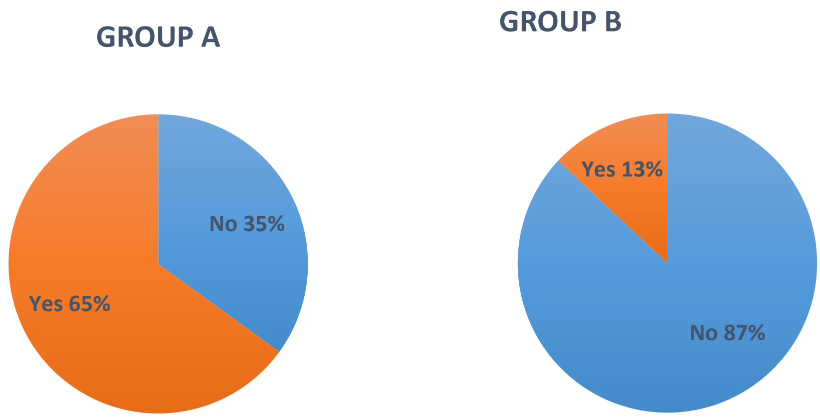


Figure 17 PCE student results: 'Were You Aware of 3D Dynamic Operations Simulation?'

4.1.2 Current PCE modules

To understand what the students think of the current PCE curriculum in UCC, the following questions were asked to both groups:

- What areas of your degree are your most favourite, least favourite and requires modern development?
- In what year of your degree would benefit from the use of DOS?
- Identify the areas of your degree course that use of this software would best fit?

These results determined if there is an opportunity for DOS to be introduced into PCE curriculum, and if so, in what area, what year and what way can it be implemented.

The first year of the PCE programme is largely common with other engineering programmes to teach all students fundamental engineering principles. In Year 1, there are two PCE modules: an introductory module (PE1003, *Introduction to Process and Chemical Engineering*), and an ethics and communications module (PE1006, *Professional Engineering Communication and Ethics*). Topics covered in both modules are summarised in *Table 4*.

Topics that are taught in PE1003 are essential for Process and Chemical Engineering and are built upon in further years in advanced modules. It is vital to develop new students' appreciation of professional ethics through application in complex problems and case studies as well as introduce new engineers to the fundamentals of effective communication and visualisation in engineering taught in PE1006.

Table 5 Year 1 PCE module topics

PE1003	**PE1006**
Dimensions, Units and Conversions,	Data Interpretation
Process Design	Constructing and interpreting Graphs and Plots
Process Diagrams	Modelling
Unit Operations	Structure and Types of Reports
Process Control	Presentation and spoken communication Skills
Material and Energy Balances,	Philosophy of Engineering
Production efficiency, Safety & Environment	Role of Engineering in society
Cost Engineering	Wicked Problems

Summarised in *Table 6* are what 1st years believe to be their favourite and least favourite area within their limited exposure to PCE program. Students were also asked to suggest an area of the programme that, in their opinion, requires modern development. Highlighted in blue is the PE1003 module or topics within that module. PE1006 is highlighted in orange.

Table 6 1st Year PCE student response: 'What areas of the degree are your most favourite, least favourite and requires modern development?'

Favourite	**Least Favourite**	**Requires Development**
Process Engineering (PE1003)	Physics for Engineers (Physics Module)	//
Process Engineering (PE1003)	Physics for Engineers (Physics Module)	Ethics (PE1006)
Plant Design (PE1003)	Environment (PE1003)	Mass/Energy Balances (PE1003)
Process Design (PE1003)	Physics for Engineers (Physics Module)	//
Building PFD's (PE1003)	//	//
P&ID (PE1003)	//	//
Mass/Energy Balances (PE1003)	Safety (PE1003)	Tutorials
Unit Operations (PE1003)	Safety (PE1003)	Engineering Materials (Civil Module) and Ethics (PE1006)
Environment (PE1003)	Stoichiometry (Chemistry module)	Safety (PE1003)
Environment (PE1003)	Engineering Materials (Civil Module)	Notes
Engineering Materials (Civil Module)	Process Engineering (PE1003)	//
Coding (Civil Module)	Mechanics (Applied Maths Module)	//
Electrical Engineering	Calculus (Math Science Module)	Mechanics (Applied Maths Module)

Given 1st year students' limited exposure to the curriculum, there are some inconsistencies within their choices. However, it is clear from these results that PE1003 or a topic covered within it was voted most popular by the students. This shows that the new students value Process and Chemical Engineering principles. The survey was conducted on the 2nd week of 2nd semester, meaning that 1st year students had only 2 weeks' worth of this module completed.

Showing this much interest and rating it higher than any other 1st year module suggests that students are indeed enthusiastic about learning Process and Chemical Engineering fundamentals, and perhaps there is an opportunity to utilise this eagerness by creating an extra element of Process and Chemical Engineering within 1st year. Potentially, DOS could add this additional level to the 1st year curriculum.

The safety and environmental element to PE1003 was voted least favourite, although it is only touched upon very briefly within the module. It is vital to gain a base knowledge of safety and environmental, given the advanced modules in the years ahead and the relevance to engineering careers. DOS as a training tool inherently increases students safety knowledge in an applied manner, therefore could act as an alternative to the more popular method of teaching the subject. The other modules deemed their least favourite were non-PCE modules.

Two students suggested that PE1006 requires modern development. However, it was not proposed by any student as a possible module/area that could benefit from DOS. One student thought that DOS could be *'beneficial to incorporate into the curriculum instead of the ethics module'*.

Results from the 1st years indicate that they are enthusiastic about process and plant design, and this is a possible area that could be developed using DOS to enhance student process awareness, operability and safety in design. Mass balances was given as both a favourite subject and least favourite subject. Mass and energy balances are a feature that can be demonstrated through DOS.

Table 7 2nd and 3rd Year PCE student response: 'What areas of the degree are your most favourite, least favourite and requires modern development?'

Year	Favourite	Least Favourite	Requires Development
2nd	Process Equipment (Topic covered in PE2011)	Mass/Energy Balances (fundamental principle in PE modules)	Numerical Methods and Programming (Applied Maths Module)
2nd	Process Design (Topic covered in PE2011)	Fluids (Civil Module)	Selection of modules, are they relevant to our future careers
2nd	Mass Balances (fundamental principle in PE modules)	Engineering Mechanics with Transform Methods (Applied Maths Module)	Fluids (Civil Module)
3rd	Plant Design and Commissioning (PE2011)	Sustainability in Process Engineering (PE3011)	Unit Operations and Particle Technology (PE3002)
3rd	Engineering Computations and Problem Solving (1st year Civil Module)	Solid and Structural Mechanics (2nd year Civil Module)	Introduction to Biochemical Engineering (PE2005)
3rd	Applied Fluid Dynamics and Thermodynamics (PE3001)	Chemical Reaction Engineering (PE2009)	Heat Transfer (PE2003)

Table 7 summarises 2nd and 3rd year students' answers when asked the same question. In Year 2 and Year 3, more specific PCE modules are introduced (highlighted in blue). In 2nd year, half of the modules taught are PCE subjects. Nevertheless, the non-PCE modules feature as their least favourite modules and all the 2nd years surveyed suggest that these modules require development. This begs the question if these non-PCE modules are absolutely relevant for PCE curriculum. Are C# and MatLab programming skills essential for preparing Process students for their future career? Reviewing the modules taught and updating the curriculum to include a 'minds-on, hands-on' process engineering software could be what is needed to best prepare students.

All of the 2nd year students chose an element of Plant Design and Commissioning (PE2011) as their favourite subject. This echoes the 1st year student's enthusiastic response to Process and Plant design modules.

In Year 3 of the program, 7 out of 9 modules are PCE modules. Students also undergo Work Placement at the end of semester 2. It is expected of employers that the students are sufficiently prepared for industry. The 3rd year student who chose Plant Design and Commissioning as their favourite module said that they *'like the idea of seeing a finished and real life product to my work'*. This 'real-life' aspect that the student appreciates can be directly comparable to the 3D virtual reality feature of DOS.

Unit Operations was chosen as a subject that requires development. One student commented that *'it's all well and good learning the theory of these unit ops, but hands on application of them would make them easier to understand'*. DOS allows the student to 'experience' a large range of unit operations from start-up/shutdown procedures to troubleshooting upsets, providing a link for the theory and practical application in industry.

The final year of the program consists of 100% PCE modules. 4th year opinions on current PCE modules are summarised in the *Table 8*. Advanced Process Design was chosen as the favourite module by the majority of the class as it *'prepares you for the life of a process engineer'*. Dynamic Simulation software packages ASPEN plus and SuperPro Designer are used in this module to model and design processes. Students evidently responded positively to this aspect of the module, which in turn makes DOS seem suitable for this module.

Table 8 4th Year PCE student response: 'What areas of the degree are your most favourite, least favourite and requires modern development?'

Favourite	**Least Favourite**	**Requires Development**
Advanced Process Design (PE4001)	Complex Reaction Systems (PE4014)	Process Dynamics and Control (PE3007)
Advanced Process Design (PE4001)	Complex Reaction Systems (PE4014)	Process Dynamics and Control (PE3007)
Advanced Process Design (PE4001)	Complex Reaction Systems (PE4014)	Process Dynamics and Control (PE3007)
Advanced Process Design (PE4001)	Complex Reaction Systems (PE4014)	Process Dynamics and Control (PE3007)
Advanced Process Design (PE4001)	Complex Reaction Systems (PE4014)	Process Dynamics and Control (PE3007)
Advanced Process Design (PE4001), Unit operations and Particle Technology (PE3002)	Complex Reaction Systems (PE4014)	Safety and Environmental Protection (PE4004)
Unit Operations and Particle Technology (PE3002)	Safety and Environmental Protection (PE4004)	Safety and Environmental Protection (PE4004)
Unit operations and Particle Technology (PE3002)	Safety and Environmental Protection (PE4004)	Safety and Environmental Protection (PE4004)
Mechanical Design of Process Equipment (PE4007)	Safety and Environmental Protection (PE4004)	Safety and Environmental Protection (PE4004)
Mechanical Design of Process Equipment (PE4007)	Safety and Environmental Protection (PE4004)	Sustainability In Process Engineering (PE3011)
Engineering Materials and Process Machinery Dynamics (PE3005)	Safety and Environmental Protection (PE4004)	Complex Reaction Systems (PE4014)
Mechanical Design of Process Equipment (PE4007), Safety and Environmental Protection (PE4004)	Mass/Energy Balances (fundamental principle in PE modules)	Linking industrial application as much as possible with all modules
Engineering Materials and Process Machinery Dynamics (PE3005)	Engineering Mechanics with Transform Methods (Applied Math's Module)	Too theoretical, no practical side which could be carried forward
Sustainability In Process Engineering (PE3011)	Applied Thermodynamics and Fluid Mechanics (PE3001)	Professional Engineering Communication and Ethics (PE1006)
Applied Thermodynamics and Fluid Mechanics (PE3001)	Process Validation and Quality (PE3013)	Advanced Process Design (PE4001)

Unit Operations featured in the students' favourites due to the '*good balance between theoretical knowledge, worked problems and solutions and laboratory practical's.'* Perhaps the Unit Operations module is already developed enough in terms of a 'minds-on, hands-on' module. Nevertheless, as mentioned, there is potential for students to engage in advanced, large scale Unit Operations in a safe manner through DOS.

Complex Reaction Systems was voted least popular amongst the final year students. Students noted that the content was *'hard to follow, the industrial link is not overly clear and the module requires more background explanation and applications'*. It is vital for Process engineers to be able to analyse reaction rate data and recognise the dynamics of reactors and the steps required to design, optimise and operate them safely. This module in UCC is purely theoretical with no dynamic software or laboratory practical. Students commented that the module '*would benefit from good software instead of using excel'*. By 'operating' and visualising a simulated percolated bed reactor or adsorption column, students may grasp the difficult concepts of the module better.

The majority of the 4th years thought Process Dynamics and Control requires modern development. One student commented that *'it is easier to learn about these subjects through hands-on experience'*. This module contains lab practicals demonstrating simplified, small scale open loop, closed loop and feedback control experiments for the student to understand fundamental control concepts. Perhaps to evaluate the dynamics of a more advanced system and to experience a DCS control screen with outside operator and view trend graphs as a Process Engineer would in industry, DOS has potential to enhance Process Control module that, according to the students, requires development.

Questions regarding the potential of DOS within the degree were then asked.

4.1.3 Suitability of DOS within PCE Curriculum

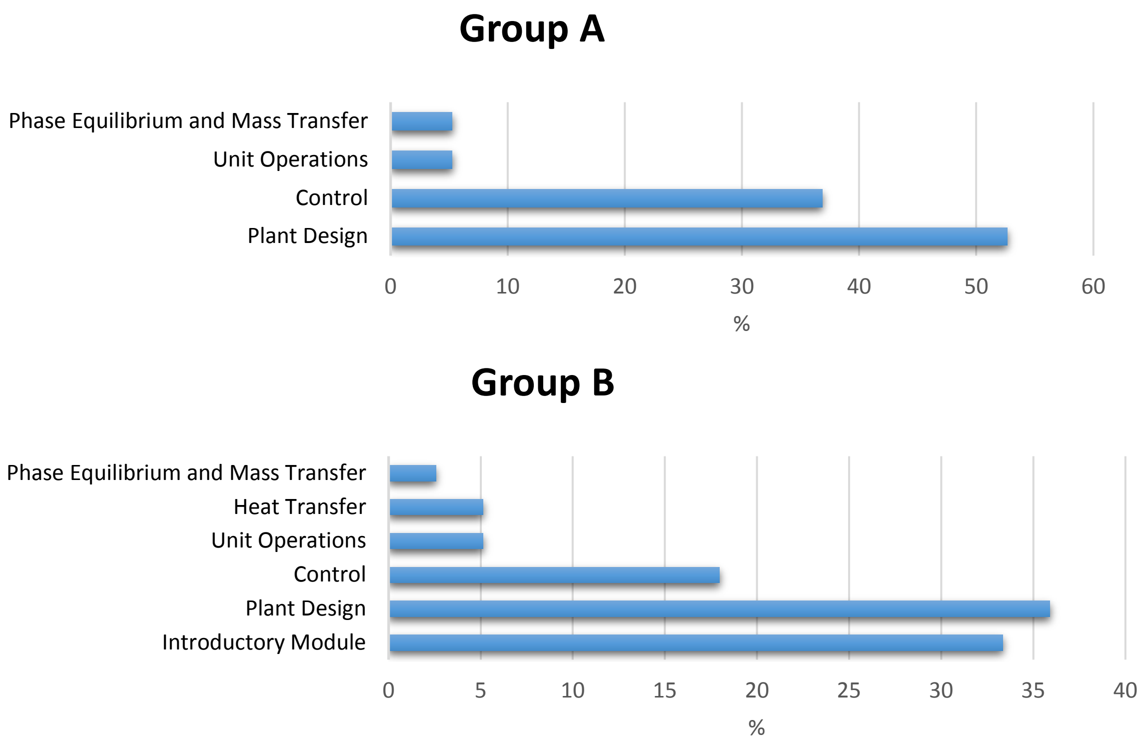


Figure 18 PCE student response: In what area would DOS best suit?

Both Group A and Group B chose process and plant design as the area in which there is an opportunity for DOS (*fig. 18*). Students also believe that DOS should be introduced into the curriculum to teach Control, with one student commenting that '*DOS should be part of process control module and used to explain different types of control*'.

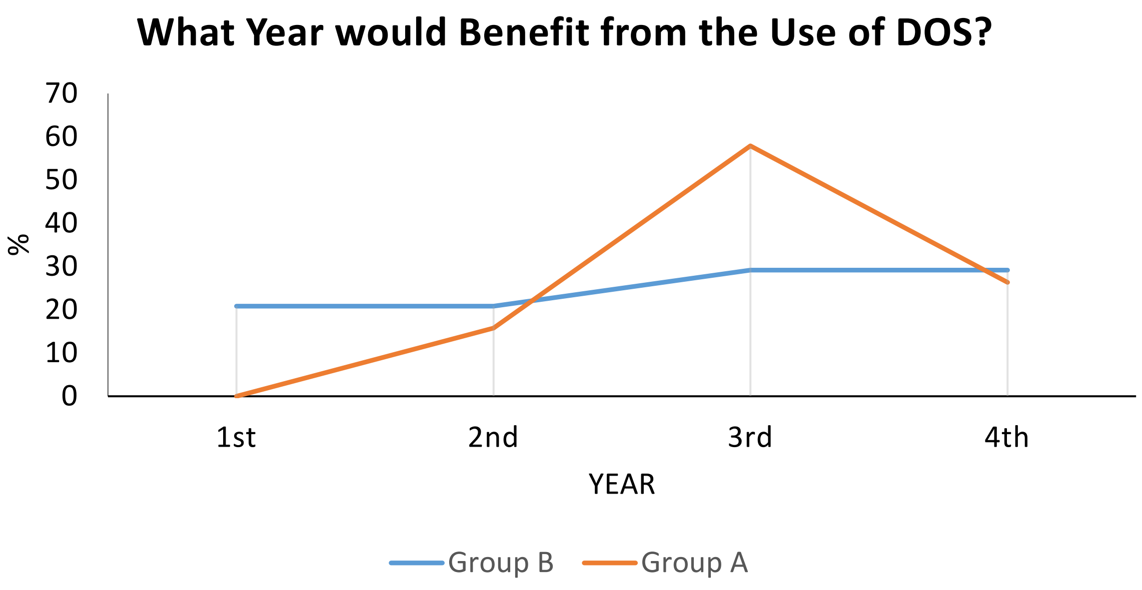


Figure 19 PCE student response: 'In what year of your degree would benefit from the use of DOS?'

60% of Group A stated that 3rd year would be the optimum year for the software to be introduced (*fig. 19*). 1st year was voted as the least beneficial year, suggesting that this software is too advanced for an introductory module and requires process knowledge prior to working with it. There was no clear consensus from Group B, which could go down to the fact that they have less of an insight into the course as a whole.

4.1.4 DOS and Hands-On Learning

Group B were asked how important they find hands-on learning. There was a general agreement that hands-on learning is vital within education (*fig. 20*).

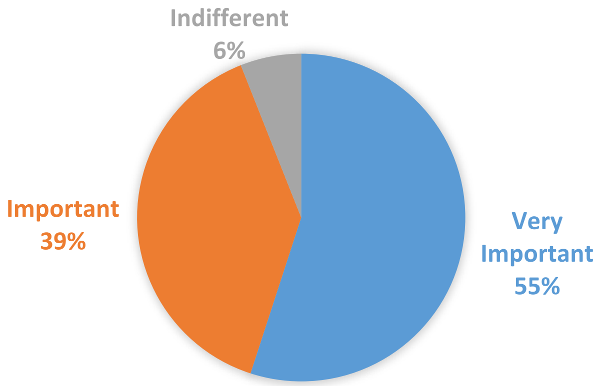


Figure 20 1st- 3rd Year PCE Student response: How Important do you consider hands-on learning in Engineering Education?

When asked if there is enough hands-on learning within the curriculum, 1st year students responded negatively, remarking that *'1st year is all just theory and is quite uninteresting'* and that *'There could be a lot more practical applications [within Year 1]'*.

2nd and 3rd years agreed with the younger year stating *'UCC relies heavily on theory and learning'* and students '*do very little hands on work throughout the course'*. Evidently, there is a need to increase hands-on learning within the curriculum. One student recognised that *'Interacting with learning materials is a much more effective learning method for some students'*. DOS can be applied as a 'hands-on, minds-on' learning tool.

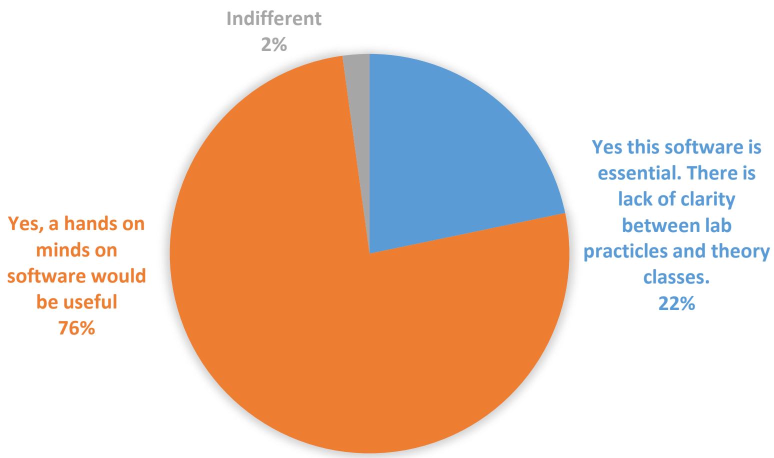


Figure 21 Do you think DOS could supplement/link theoretical material learned in class and practical laboratory work?

All students believe that from what they saw of DOS software, it could adequately supplement labs and link theory in class to practical processing industry applications. One student commented that *'Labs don't exactly teach you enough for industry'*. Students highlighted the fact that laboratory practicals are proving difficult with the growing numbers in Process and Chemical engineering classes *'lab work is not practical due to large numbers'*. Some Process and Chemical practicals in UCC are forced to be carried as demonstrations instead of hands-on work by the students. Students feel that these demonstrations are *'pointless and we don't get much from them'*.

The introduction of DOS into Process and Chemical Engineering curriculum could rectify this problem and allow each student to individually apply their engineering knowledge at their own pace and level of standard. One 3rd year student stated that the software *'adds a practical and real life dimension to the course but on a much more accessible level for large numbers of students.'* Dynamic Operations Simulation also permits students to experience advanced industrial applications safely in non-real time.

4.1.5 Incorporating DOS into PCE Education

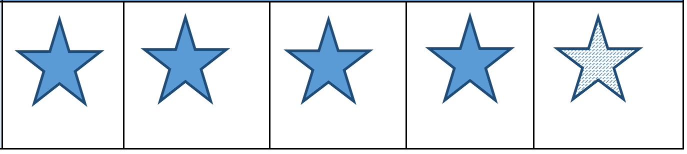
Question	Star Rating
Was the DOS workshop of added value to your Process and Chemical Engineering knowledge?	

Figure 22 4th Year PCE Student response: 'Was the DOS workshop of added value to your Chemical Engineering knowledge from 3rd level education?'

4th years were asked if the DOS interactive workshop built upon their current Process Engineering knowledge (*fig. 22*). 100% of the group voted yes, immediately showing the impact DOS can make to even advanced level students. The '*interactive environment'* of the workshop helped them to *'understand process control'*. The *'process of working [the exercises] out in groups beforehand made for a more interactive and hands-on learning approach'*. According to one student, *'from just the one tutorial it gave a good overview of how all the different variables can influence one another'*. The exercises given to the final years were challenging for them as one student noted '*Some bits were counter intuitive, but the reason was explained why. More sessions would be good, as one probably wasn't enough'*. It is without doubt that DOS can advance student Process and Chemical engineering knowledge.

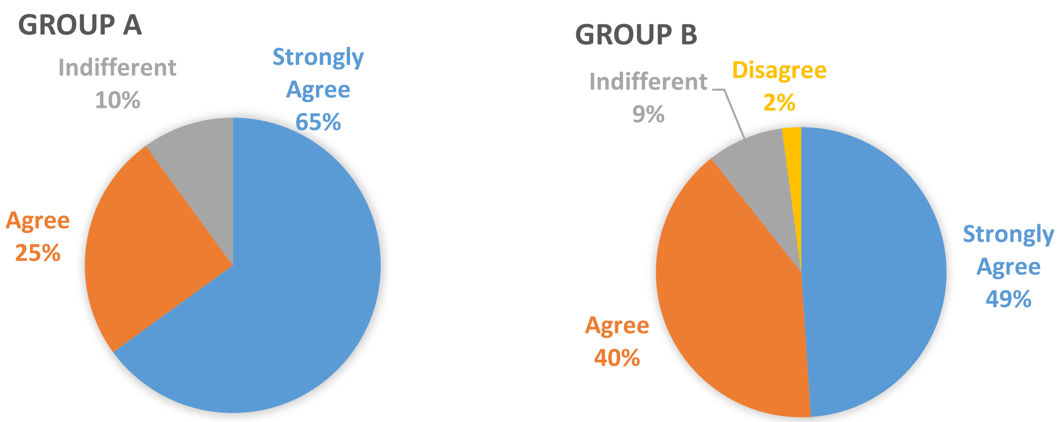


Figure 23 PCE Student Response: Should this type of (interactive) Dynamic Process Operations Simulation be incorporated into Chemical Engineering Degree courses?

When asked whether this type of interactive DOS software be incorporated into the Chemical Engineering curriculum, 4th year students were overwhelmingly positive (*fig. 23*). 90% of the group agreed that it should be introduced, with 65% of the group giving the statement 5 out of 5 stars. One of the reasons given for the strong agreement was that: '*Theoretical knowledge is* *wasted if the application of the acquired information is not put to use as it will be in the working environment'*

The remaining 10% were indifferent, ranking the statement 3 stars. The students who gave this ranking, however, were still positive about putting DOS to use in education. They commented that the '*Interactive nature helped in understanding [the plant]'*. One student noted that '*it really bridges the gap between what you learn in college and how to apply it in industry'*. The final year students were impressed by the potential DOS could have in engineering education. One student noted that DOS shouldn't be a module by itself, but rather *'incorporated into another module'* to enhance areas within the curriculum that lack a hands-on practical element. DOS allows students to see *'theory in action'* as the software is *'Very beneficial for illustration and elucidation of cause-&-effect in process operations'*. Overall, the 4th year students agreed that there are opportunities for DOS in the PCE curriculum.

Group B also responded positively, with 89% of students agreeing that DOS should be incorporated into the curriculum. One 1st year student disagreed slightly, giving the statement 2 stars out of 5. The rating was backed up by saying that the interactive DOS workshop was *'a bit straightforward and there isn't much of a need to teach* ***it***, ***it*** *can be picked up fairly easily in the work place.'* There is uncertainty whether the 'it' in question is in relation to the software itself or operational readiness and awareness. Nevertheless, this particular student was aware of DOS prior to the workshop, so it is understandable that the interactive demonstration seemed too simple for them. This student experienced DOS as a demonstration aimed for a group of inexperienced Engineering students. If DOS was implemented into the curriculum, exercises and modules could be tailored for each individual, depending on their level.

Another individual who was also aware of DOS and has had experience in industry, strongly agreed that the software should be introduced into the curriculum and commented that it is an *'invaluable program'*. One student noted that being exposed to DOS would *'make the transition into a career in industry a lot easier'* because *'working with this type of program would give students an insight into what it's like to actually work with a chemical process on a plant'*. One 1st year saw the potential of DOS as a *'helpful way to show how theoretical* *topics translate to the real world without having to actually go to plants regularly'*. One second year student thinks DOS could help as they admitted that they '*still struggle to relate a lot of what we do to practical applications that we'll actually experience in the workplace and [DOS] could help bridge that gap'*. One 3rd year student stated that *'This software would allow us to build a real life image of different pieces of equipment. The ability to watch how different parameters effect the outcomes would allow intuitive learning'*.

4.1.6 DOS after 3rd Level

The majority of the students agreed that there is potential for DOS to be used to train Process Engineers in industry after they graduate (*fig. 24*).

Students believe that DOS can be used to *'constantly upskill and keep up with the changing world of technology'*. The bulk of the students noted that DOS could be useful for troubleshooting and testing different process variables when '*exposed to new situations in a safe manner'*, with one first year noting that DOS has the potential to '*prevent accidents on site'*. One student recognised DOS gives the user *'confidence in troubleshooting'*, which is vital for new Process and Chemical Engineers.

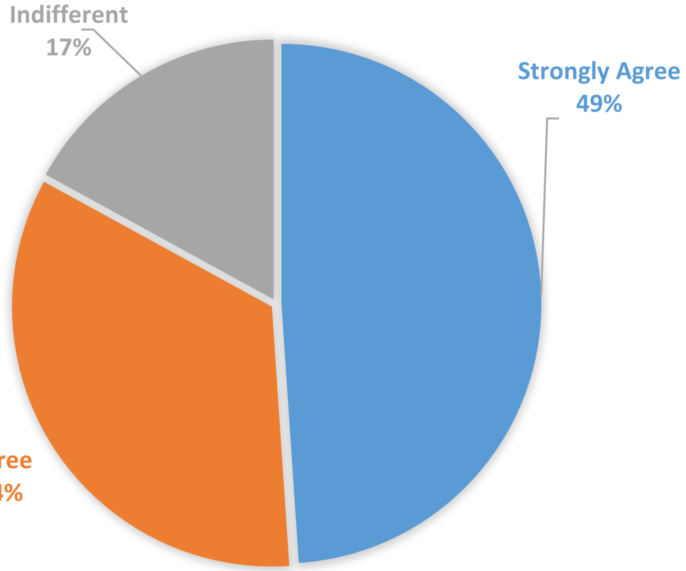


Figure 24 PCE Graduate response: 'Do you think DOS would be of benefit in graduate engineering programs?'

4.2 Graduate

A survey was given to the Graduate Engineer prior to the 1-on-1 DOS demonstration. This was carried out with the intention of getting a young Process Engineers' opinion on how well the PCE program prepares students for industry. The Process and Chemical Engineer has 5 years' experience in Automation in a bio-pharmaceutical plant and deals with the day to day support of the plant and troubleshooting of issues.

4.2.1 What area of the PCE curriculum best prepared you for work?

When asked this question, the engineer chose Research/Design projects (4th year), stating that *'working in groups to achieve a shared goal, time management and what is actually involved in design & functional specification preparation'*. It should be noted that the graduate did not select the other options: Laboratory Practicals or Theory Classes as aspects of the curriculum to best prepare students for industry.

4.2.2 What can be improved and/or introduced into the curriculum to best prepare students entering the work force?

The graduate stated that the curriculum needs '*More interaction with other aspects of the pharma industry (i.e. health & safety and operations). This would help with communication while working alongside these departments in industry'*. Before even being introduced to the purpose of this research, the graduate highlighted the importance of operational and safety knowledge for Process Engineers.

Following the 1-on-1 session with DOS, the following questions were proposed to the graduate Process and Chemical Engineer about the potential of the software in industry and in engineering education.

4.2.3 Can DOS prepare PCE students for industry?

Question	Star Rating				
Would you have been more prepared entering your job role as a graduate if (DOS) was a part of the PCE curriculum?	★	★	★	★	★

Figure 25 PCE Graduate response: 'Would you have been more prepared entering your job role if DOS was a part of the PCE curriculum?

The graduate believes entirely that DOS can prepare students for industry (*fig. 25*). The graduate stated that DOS could 'prepare *you for troubleshooting issues in live production such as pump failures, temperature/pressure deviations etc. It would also give you an* *understanding in how changing control set points on a piece of process equipment could have an effect on efficiency and/or safety of said equipment'*. Evidently, DOS as a learning tool for students at university level would help to develop more industry-ready Process and Chemical Engineers.

4.2.4 Based on your experience with DOS, how best would the software be incorporated into the curriculum?

The graduate engineer thought 3rd year would be the best year to introduce DOS '*when the student has a firm base in the theory of process equipment'*. According to the graduate, in order to gain full potential of DOS, it would be best introduced when the student has a high level of theoretical knowledge. It was added that '*It would be best taught in an interactive environment where each student has the programme in front of them and are given instructions/problems to solve individually'*. To obtain the benefits of the software, a demonstration is not effective and students should be able to work with the DOS individually.

4.2.5 Does DOS have the potential to improve situational awareness and operations knowledge for Process Engineers in industry?

The graduate made the valid point that DOS *'would encourage engineers to take into account factors/effects that might be overlooked while trying to optimise a piece of equipment or upgrading a device i.e. installing a larger pump*'. DOS training expands operations knowledge and subsequently optimisation and safety of the plant, ultimately reducing losses. The graduate noted that DOS training in industry for Process Engineers could *'help an engineer appreciate the work that operators do and the challenges they encounter on a daily basis'* thus strengthening communication between engineering and operations, improving the efficiency of the plant.

4th year students were also asked how important they consider operational awareness for Process and Chemical Engineers in industry. With an average agreement of 4.5 out of 5 stars, the response is strongly positive meaning that the final years deem operational and situational alertness just as critical for Process and Chemical Engineers as it is for Operations staff too and a training tool should be implemented in order to develop employee competence.

Students believe that operational awareness is necessary to *'communicate effectively with the operator/control room'*. A strong relationship between Process Engineers and Operations staff is *'important for everyday running, but more important for when a problem arises, there is already a common understanding of what should be occurring and what problems have been highlighted.'* DOS can help students with *'envisioning the process and being able to predict any changes to it'*. Excellent troubleshooting training is a vital factor of developing operational and situational awareness.

Training Process and Chemical Engineers with a Dynamic Operations Simulation tool can *'Provide an understanding of the work that the operator/technician carries out, helping build the mutual understandings and support the development of that relationship'*.

4.2.6 What area within the Process industry could DOS be used as a training tool?

The PCE graduate suggested that DOS could be used in training for every area within industry, showing the broad range of potential for DOS for Process Engineers. '*It would give engineers/operators a chance to understand the plant by "playing around" with the equipment in a safe environment, helping them to understand the various factors and what role they play in the plant and when/where/how they come into effect'*.

4.3 Clients of DOS

Survey results from Operators that have attended Simulation Solution's 2-day training course were gathered to form a complete industry perspective of DOS as a training tool. Those surveyed were all current Console Operators at Major US Oil Refineries.

The participants were asked **'What will you do differently because of taking this course?**' Answers given included:

- *Operate more efficiently and think twice before reacting.*
- *Take time and think things through with the process of elimination.*
- *Think through all effects of a variable changing and use time to practice troubleshooting.*
- *Print out DCS Screens & review cause & effect with engineer when troubleshooting*
- *Analyse first before taking action.*
- *Think "what if" before making moves on board.*

The training course given to staff evidently made a positive impact in how they work, directly affecting their method of troubleshooting and operating, which in turn affects plant safety and efficiency.

The exercises they found to be most helpful in improving skills (*fig. 26*) are 'What-If' exercises and troubleshooting exercise. These exercises are, therefore, the most applicable to industry. This feedback from clients of DOS was taken into account when developing recommendations for DOS in education and for graduate training.

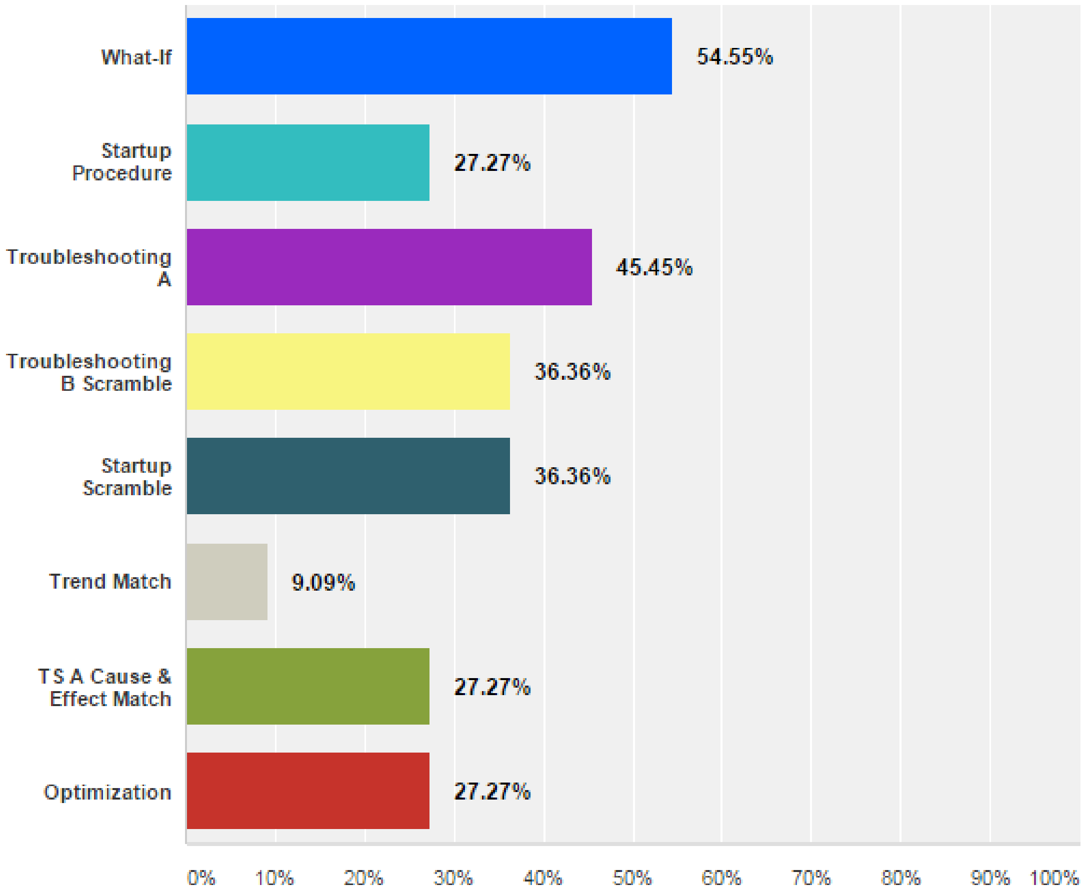


Figure 26 Exercises Clients of DOS find most helpful

4.4 RECOMMENDATIONS

4.4.1 1st Year

Although it is paramount that PCE students first learn the theory behind fundamental engineering principles such as physics, materials and chemistry, it is just as vital for these students to 'experience' real life plant situations as early as possible to begin thinking and acting like Process and Chemical Engineers.

Introducing a DOS element within the introductory module **PE1003,** which proved popular among 1st year students, could give them an initial 'hands-on' learning that can activate their critical thinking and familiarise themselves with P&ID's, general unit operations and processes. After a general run through of the software simulating a generic reactor and a *process description* describing the function and mass/energy balances of the reactor, students could undertake *DCS-P&ID matching* and *outside operator identification* exercises to apply theory that they learned from classroom. Allowing students to manually manipulate variables outside and relating these changes back to the DCS trains them to begin understanding the operations of a plant.

4.4.2 2nd Year

There is an opportunity for DOS in **PE2011** Plant Design and Commissioning module. DOS allows students to essentially operate a modern process plant facility, inherently applying their process safety knowledge and plant management skills, both topics which are covered within the module. A distillation column module could be used. The students could be given '*what if*' exercises to teach them how to predict and identify problems.

4.4.3 3rd Year

There is a lot of opportunities within 3rd year modules for DOS. The first is within Process Dynamics and Control (**PE3007).** DOS could help students to evaluate the dynamics of a system, analyse control systems for equipment. Experience trends and alarms that a control room operator faces in industry. This type of hands on work is invaluable for students learning process control. Perhaps supplementing the PE3007 laboratory practices, students would develop operational control skills and help visualise theory in a 'real-life' situation. *Trend match* exercise would be invaluable within this module.

Unit operations (**PE3002**) in 3rd year could also avail of DOS. Simply using the software to teach students proper start-up and shut down techniques both help the students to understand unit operation performance, but also prepares students for large scale operations they will see in industry, inherently developing more operationally aware engineers. Beginning with *start-up/shutdown scramble* exercises and advancing to performing emergency start-ups and shutdowns is invaluable experience for students when learning about unit operations.

4.4.4 4th Year

Troubleshooting exercises are vital to final year engineers as they can apply their knowledge so far in a real-life plant situation and increase situational and operational awareness. Cause and effect exercises could potentially enhance **PE4001**, the 'Advanced Process Design' module. Process design software is used within this module, so given the added dynamic operations element in DOS, there is excellent potential within this module. Advanced modules can challenge the students to increase their Process and Chemical Engineering knowledge.

4.4.5 Graduate in Industry

Troubleshooting and *optimisation* exercises should be mandatory for Engineers entering industry. Training new Process and Chemical Engineers using high fidelity customised modules that replicate actual plant, DOS would upskill the graduate quickly and increase competency. In turn, the plant would see higher productivity and less accidents, ultimately preventing losses. Communications between Engineers and Operations staff would improve. Challenging exercises throughout their career constantly develop their skills and make them more operationally aware engineers.

4.4.6 Summary of Results

Year	**1**	**2**	**3**	**4**
Module	Introduction to Process & Chemical Engineering	Plant Design& Commissioning	Process Dynamics and Control	Design Project (Design Memo)
Objectives	Fundamental understanding of selecting process alternatives, applying control strategies	Operation of a modern process plant facility	Dynamics of a control system for processing industry equipment	*Case Study*: Unit Operation HAZOP, Start-up/Shut-down procedure, operation agility & understanding

Industry	
Objectives	**Exercises**
Practise troubleshooting for emergencies on plant	Unknown upset, start-up/shut down procedures

5. Case Study

This research has explored the broad range of opportunities DOS offers to Process and Chemical Engineering. The following case study focuses on an application of DOS within PCE education, incorporating all elements of DOS discussed thus far.

5.1 Module Description

DOS can be used to test, analyse, explore and learn about all **safety** issues related to process **design**, technological characteristics and procedures of the unit (Simulate Live, 2017). Survey feedback concluded that students would like to see DOS utilised within **design** modules and the graduate Engineer noted that DOS could be used as a hands-on tool to enhance student **operations** knowledge. Encompassing all of these potential benefits of DOS, the 'Design Project' (PE4006) was chosen as the module in which to integrate DOS for this case study.

This group project is described by the graduate engineer as the most applicable PCE module in UCC that prepares students for industry. Students are required to develop a full design of a new manufacturing facility to produce a specified chemical or product. As part of the project, each student is tasked with creating a Design memo for a specific unit operation. A **safety analysis** is essential for this individual memo, where students are required to:

- Identify the variables that need to be monitored and controlled and subsequently put controllers in place,
- Identify potential hazards and perform a basic risk assessment (HAZOP) of the unit operation,
- Outline Unit operability, i.e. start-up and shut down procedures.

DOS as a resource tool for the individual unit operation design memo for PE4006 students is outlined in this case study. Giving students access to a Dynamic Simulation of a standard unit operation would allow them to complete the objectives in a minds-on, hands-on manner. For the purpose of this case study, the DOS Software Package is Simulation Solutions Inc. and the Unit Operation is a Binary Distillation Tower.

5.2 Control

A control philosophy of a model distillation tower is explained within the exercise booklet provided. The main control parameters of a distillation tower are **feed rate, reflux rate, tower temperatures** and **tower pressure**. Every controller seen on the DCS graphic is described and justified. An example of the control philosophy is described below:

"Distillation Column pressure is controlled by PIC-120. This PIC controls two valves, in the following manner: if pressure in the system starts to fall, the control valve (A) that allows some of the warm vapours to bypass the overhead condenser will open to bring pressure up to the set point. Should pressure conditions increase above the set point, the vapour bypass valve (A) will close and the vent valve (B) will open. Design is for the valve (B) in the vent line to be slightly open, and the valve (A) that allows vapours to bypass the condenser to be closed. Hand valve HV-125 must be open. Should HV-125 fail closed or inadvertently be left closed, the Overhead Condenser fails, the cooling water fails, etc., a Safety Relief Valve (SRV) will open at 1.3 KG/CM2 to protect the column. In which case, enough vapour to maintain this pressure is routed through an auxiliary flow path directly to the Vent".

By manipulating operating variables on the DOS, effects to the control parameters can be evident:

TOWER PRESSURE Increasing the tower pressure will require higher temperatures throughout the tower to maintain the same quality of products. Lowering the pressure will reduce the temperatures in the tower, but may make it impossible to condense the overhead. Generally, a tower is operated at the minimum pressure that will allow condensation of reflux and/or the overhead product.

REBOILER STEAM RATE Increasing the reboiler steam rate will produce more boil-up which will require more reflux to maintain the same product quality. This increases traffic in the tower, and may overload the tower even at low feed rates. Increasing the steam rate without a concurrent increase in reflux will increase the bottoms temperature, and reduce the concentration of light ends in the bottom product. Lowering the steam rate will increase the light ends in the bottoms product, and lower the bottom temperature

REFLUX RATE An increase in reflux rate will reduce the concentration of heavy ends in the overhead product. A decrease in reflux flow will increase the heavy ends in the overhead product. Without top temperature control, an increase in reflux will decrease the top tower temperature. Conversely, a lower reflux rate will increase the top tower temperature.

BOTTOM TOWER TEMPERATURE An increase in bottom temperature will decrease the light material in the bottoms product. Alternately, reducing the bottoms temperature will increase the light ends in the bottoms product.

TOP TOWER TEMPERATURE Increasing the top tower temperature will allow more heavy material in the overhead product. Lowering the top tower temperature will allow less heavy material into the overhead product.

This gives the student both a theoretical and applied level of detailed control specific to their given unit operation. This is crucial for identifying variables that need to be monitored and controlled.

5.3 HAZOP

'What-If' questions can be easily answered and visualised on DOS when developing a HAZOP for the unit operation. Students can visually see changes on plant, audible alarms sound if parameters go outside of control specifications and also trend displays make what if analysis much more comprehensible. They are a feature on the DCS that graphically show how a process variable changes over time with the ability to show multiple process variables on a single display.

Potential hazards of Distillation Towers are described below:

- Cooling water flow should be established before heating the reboiler during start up to prevent overheating equipment and potential hazards.
- Temperatures of the boiler and column can be extremely hot. Caution should be used when operating outside equipment to avoid burns.
- Heat exchangers in the process can provide a source of ignition and a potential for a fire if a leak occurs.

- Temperature, pressure and reflux must be controlled within operating parameters to prevent thermal cracking in the distillation tower.
- Relief systems should be provided and used if overpressure were to occur.
- Do not allow reboiler or reflux drum to overfill or run dry.

5.4 Operability

Start-up and Shutdown Procedures

The purpose of this exercise is to operate the proper sequence of actions that are required to place a process unit online in a safe and orderly manner. Actual start-up of a distillation system may take 4 to 6 hours in actual practice, but the simulator compresses this time and it should take between 30-60 minutes to complete this exercise. These procedures are not currently covered in the PCE curriculum in UCC. Given the broad range of unit operations that would need to be covered, it would not be feasible to teach at a classroom level. Students can teach themselves at their own pace in a 'minds-on, hands-on' manner.

For example, to begin the system start up, cooling water flow must first be established (*fig. 27*). It is important to establish a cooling water flow to the condenser before the reboiler liquid is heated to prevent equipment overheating and other safety hazards. To condense all of the vapours, a large water flow should be set and the hot vapour bypass control valve should be closed. Students are brought through the procedure as if they were operations staff and control room engineers.

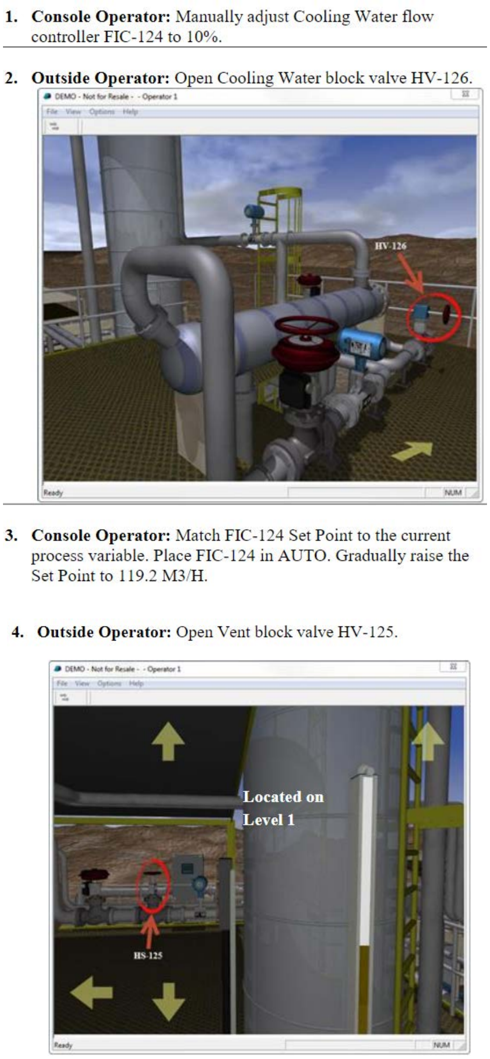


Figure 27 System Start-Up

DOS can be used as a resource for students taking PE4006 to enhance operations knowledge and agility to create comprehensive, advanced design memos.

6. Conclusion

The state of the art review revealed the broad range of opportunities that exist for DOS as a training tool and learning tool for Process and Chemical Engineers. DOS training for Operations staff has been proven to be vital to increase plant safety and employee competency. Clients of DOS stated that training with the software allowed them to operate and troubleshoot more efficiently. Following a 1-on-1 DOS session, the PCE graduate agreed that exposing Process and Chemical Engineers to DOS training can further reduce losses in industry by making Engineers more operationally and situationally aware by allowing them to experience operational plant behaviour and practice troubleshooting in a safe manner.

Blended classroom teaching is recognised as an effective modern teaching method. 3^{rd} level institutions that have integrated DOS into PCE curriculums have proven to increase student control, safety and operations knowledge. Following DOS workshops, PCE students of UCC were overwhelmingly positive to the prospect of introducing DOS into the curriculum. Process and Plant Design was voted the most popular amongst PCE students. Harnessing this enthusiasm and developing operational and problem solving skills by using DOS is a strong potential learning tool within this module. Students also suggested the benefits of introducing DOS-based coursework within Process Safety and Control modules. A case study that explored the use of DOS in a final year unit operation design memo concluded that DOS can contribute to HAZOP analysis, start-up and shut-down procedures and operation agility which is not highly covered within the current curriculum but expected of PCE students.

Real-world engineering entails a great deal of problem solving, and tools such as DOS would encourage critical thinking from students on practical engineering situations, potentially improving their intrinsic engineering competency.

One thing that has been made clear over the course of this research is the exciting potential of Dynamic Operations Simulation.

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Appendices

APPENDIX A – ABSTRACT

The Application and Assessment of Dynamic Operations Simulation in Chemical Engineering Education & Industry

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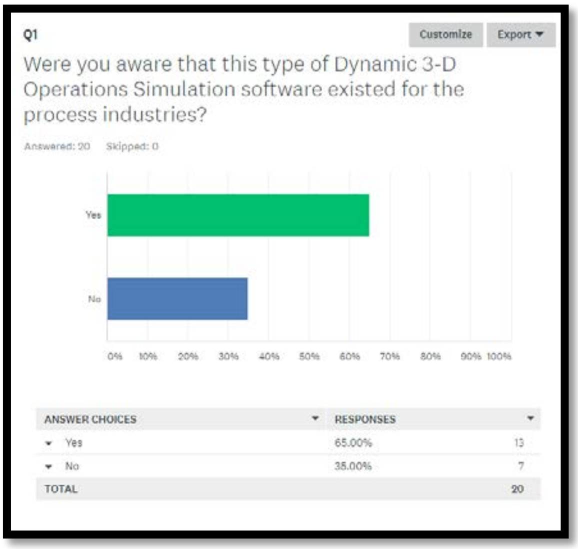
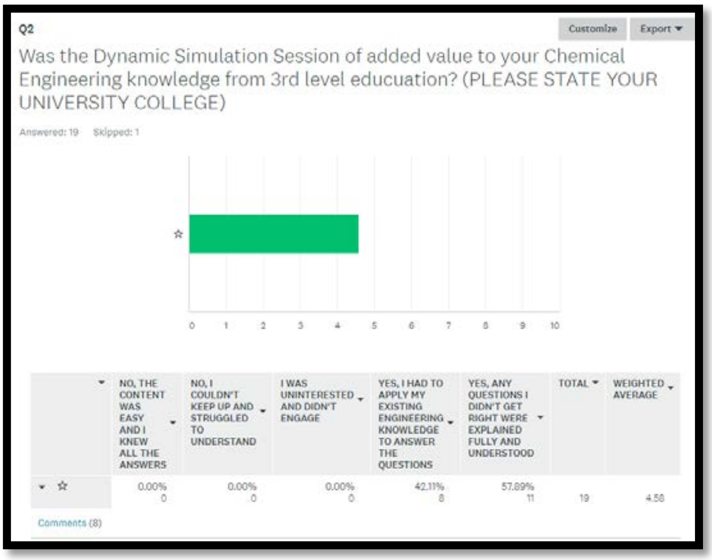
$10 billion of losses in the US processing industry are directly attributable to human incompetence when faced with avoidable plant operation upsets. Dynamic Operations Simulation (DOS) has been proven to effectively improve operation knowledge and understanding. Although Process and Chemical Engineers are an integral factor in plant operations, this training tool is used primarily for Operations staff only. This research was carried out with the aim to assess the potential benefits of DOS as a training and learning tool for Process & Chemical Engineers. Following extensive research into DOS and work already carried out in the field, the capabilities of DOS in industry and how it can contribute to influencing plant safety and performance of operations was evaluated by gathering survey feedback from clients of DOS. Further to this, a bespoke DOS training workshop was given to Process and Chemical Engineering (PCE) graduates working in industry and a survey was carried out. The research also aimed to investigate the integration of DOS into the modern PCE curriculum as a 'minds-on, hands-on' learning tool to harvest more operationally ready graduates. An interactive DOS demonstration was given to PCE students of UCC along with a survey to assess DOS as a solution that can contribute to the Process and Chemical engineer's skill set. The research showed that users of DOS in industry approved of DOS as a means of gaining confidence with troubleshooting and operating more efficiently on plant. The graduate engineers strongly agreed that DOS should be a part of the PCE curriculum as it would improve communication between engineering and operations. PCE students responded positively to DOS, stating that a visual hands-on learning tool can help to apply theoretical learning to real-life situations. A case study that explored the use of DOS in a final year unit operation design memo concluded that DOS can contribute to HAZOP analysis, start-up and shut-down procedures and operation agility which is not highly covered within the current curriculum but expected of PCE students. Process Design and Process Dynamics & Control were concluded as modules that would benefit most from DOS. It was concluded that DOS should indeed be used as a training tool for Process Engineers in industry and integrated into PCE education as a learning tool.

APPENDIX B – POSTER

APPENDIX C - SURVEY SENT TO 4TH YEAR PCE STUDENTS



ANSWER CHOICES	RESPONSES	
Yes	65.00%	13
No	35.00%	7
TOTAL		20



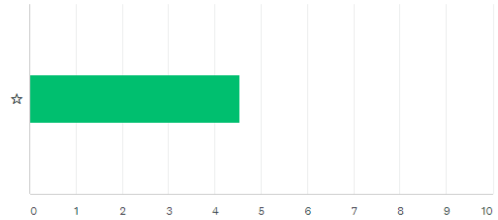
	NO, THE CONTENT WAS EASY AND I KNEW ALL THE ANSWERS	NO, I COULDN'T KEEP UP AND STRUGGLED TO UNDERSTAND	I WAS UNINTERESTED AND DIDN'T ENGAGE	YES, I HAD TO APPLY MY EXISTING ENGINEERING KNOWLEDGE TO ANSWER THE QUESTIONS	YES, ANY QUESTIONS I DIDN'T GET RIGHT WERE EXPLAINED FULLY AND UNDERSTOOD	TOTAL	WEIGHTED AVERAGE
☆	0.00% 0	0.00% 0	0.00% 0	42.11% 8	57.89% 11	19	4.58

Comments (8)

Q3 Customize Export

Should this type of (interactive) Dynamic Process Operations Simulation be incorporated into Chemical Engineering Degree courses? (5 stars=strongly agree)

Answered: 20 Skipped: 0



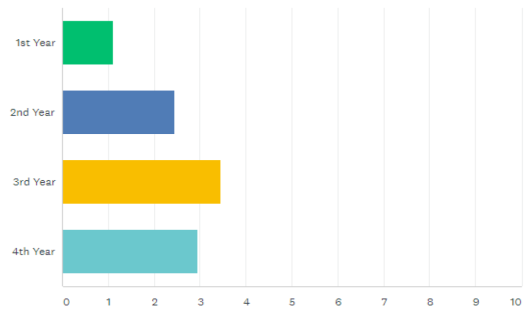
	1	2	3	4	5	TOTAL	WEIGHTED AVERAGE
☆	0.00% 0	0.00% 0	10.00% 2	25.00% 5	65.00% 13	20	4.55

Comments (8)

Q4 Customize Export

In what year of your degree would benefit from the use of Dynamic Process Operations Simulation? (please rank, 1= the best year)

Answered: 20 Skipped: 0



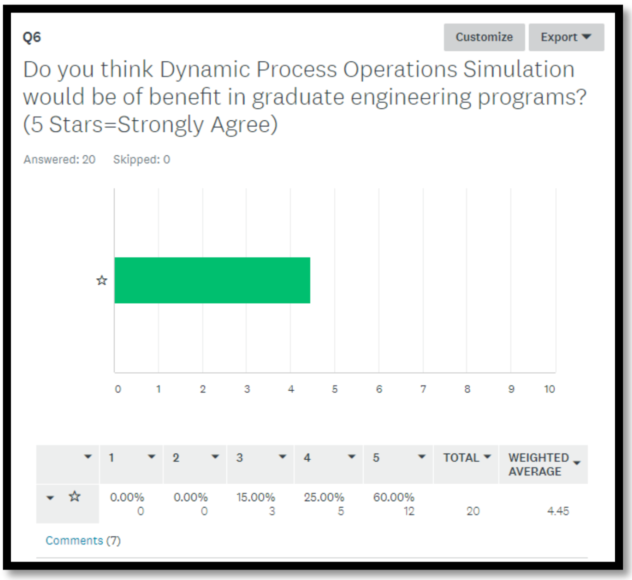
	1	2	3	4	TOTAL	SCORE
1st Year	0.00% 0	5.56% 1	0.00% 0	94.44% 17	18	1.11
2nd Year	16.67% 3	11.11% 2	72.22% 13	0.00% 0	18	2.44
3rd Year	55.00% 11	35.00% 7	10.00% 2	0.00% 0	20	3.45
4th Year	27.78% 5	44.44% 8	22.22% 4	5.56% 1	18	2.94

Q5 Export

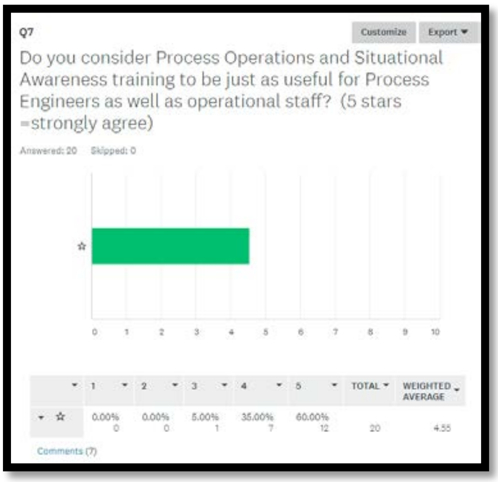
Please identify the areas of your degree course that use of this software would best suit? (In order of preference, please give module name and brief description)

Answered: 19 Skipped: 1

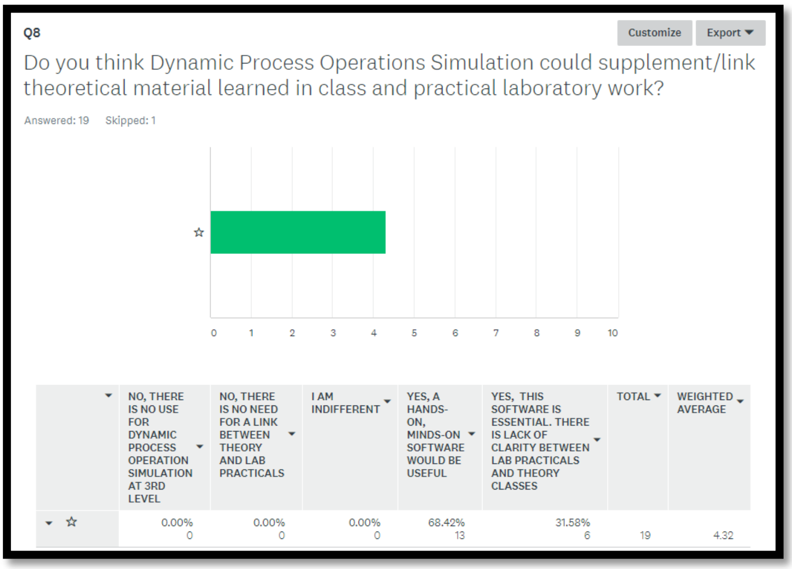
ANSWER CHOICES		RESPONSES	
1.	Responses	100.00%	19
2.	Responses	94.74%	18
3.	Responses	73.68%	14



	1	2	3	4	5	TOTAL	WEIGHTED AVERAGE
☆	0.00% 0	0.00% 0	15.00% 3	25.00% 5	60.00% 12	20	4.45



	1	2	3	4	5	TOTAL	WEIGHTED AVERAGE
☆	0.00% 0	0.00% 0	5.00% 1	35.00% 7	60.00% 12	20	4.55



	NO, THERE IS NO USE FOR DYNAMIC PROCESS OPERATION SIMULATION AT 3RD LEVEL	NO, THERE IS NO NEED FOR A LINK BETWEEN THEORY AND LAB PRACTICALS	I AM INDIFFERENT	YES, A HANDS-ON, MINDS-ON SOFTWARE WOULD BE USEFUL	YES, THIS SOFTWARE IS ESSENTIAL. THERE IS LACK OF CLARITY BETWEEN LAB PRACTICALS AND THEORY CLASSES	TOTAL	WEIGHTED AVERAGE
☆	0.00% 0	0.00% 0	0.00% 0	68.42% 13	31.58% 6	19	4.32

Q9 Export

In general, what areas of your degree are your: most favorite, least favorite and requires modern development? (e.g. unit ops, mass/energy balances, safety, environment etc...). Please give a brief explanation why.

Answered: 16 Skipped: 4

ANSWER CHOICES		RESPONSES	
Favorite:	Responses	100.00%	16
Least Favorite:	Responses	100.00%	16
Requires Development:	Responses	93.75%	15

Q10 Export

Any additional comments would be really appreciated to gain an understanding of student feedback. e.g. what you like/dislike about the software, is it user friendly, do you think it is a waste of time? etc.

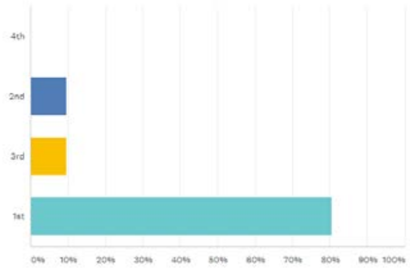
Answered: 7 Skipped: 13

APPENDIX D - SURVEY SENT TO 1ST-3RD YEAR PCE STUDENTS

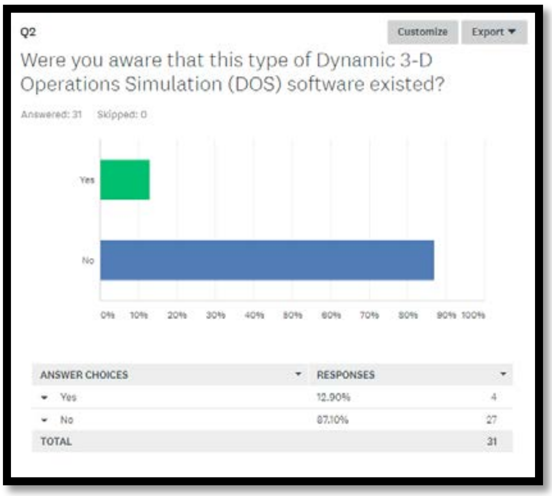
Q1 Customize Export

What year are you in?

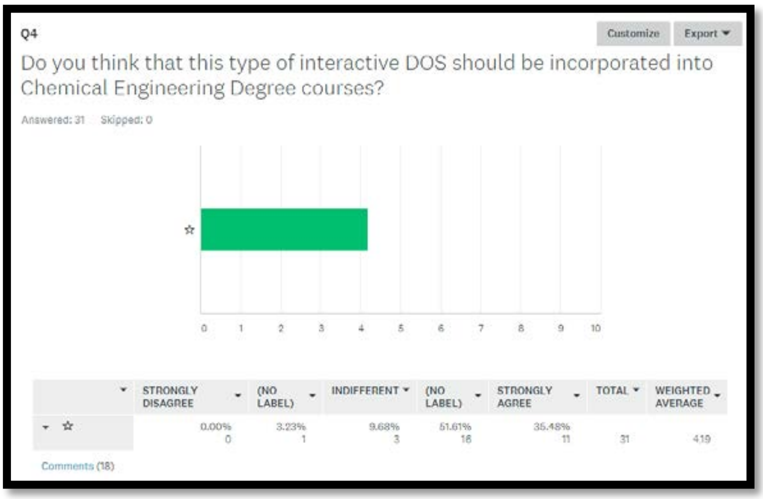
Answered: 31 Skipped: 0



ANSWER CHOICES	RESPONSES	
4th	0.00%	0
2nd	9.68%	3
3rd	9.68%	3
1st	80.65%	25
TOTAL		31


Q2
Customize
Export
Were you aware that this type of Dynamic 3-D Operations Simulation (DOS) software existed?
Answered: 31 Skipped: 0
Yes
No
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
ANSWER CHOICES
RESPONSES
Yes 12.90% 4
No 87.10% 27
TOTAL 31


Q3
Customize
Export
From your course so far, how important do you consider hands-on learning in engineering education?
Answered: 31 Skipped: 0
0 1 2 3 4 5 6 7 8 9 10
NOT IMPORTANT AT ALL, THEORETICAL CLASSROOM BASED LEARNING IS EFFECTIVE ENOUGH
NOT IMPORTANT
INDIFFERENT
IMPORTANT
VERY IMPORTANT, HANDS-ON LABS ARE CRUCIAL TO EXPAND OPERATIONS AND SITUATIONAL AWARENESS KNOWLEDGE
TOTAL
WEIGHTED AVERAGE
0.00% 0
0.00% 0
6.45% 2
38.71% 12
54.84% 17
31
4.48
Comments (22)

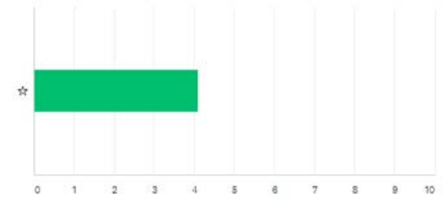

Q4
Customize
Export
Do you think that this type of interactive DOS should be incorporated into Chemical Engineering Degree courses?
Answered: 31 Skipped: 0
0 1 2 3 4 5 6 7 8 9 10
STRONGLY DISAGREE
(NO LABEL)
INDIFFERENT
(NO LABEL)
STRONGLY AGREE
TOTAL
WEIGHTED AVERAGE
0.00% 0
3.23% 1
9.68% 3
51.61% 16
35.48% 11
31
4.19
Comments (18)

Q5

Customize Export

Do you think DOS could supplement/link theoretical material learned in class and practical laboratory work?

Answered: 31 Skipped: 0



	NO, THERE IS NO USE FOR DYNAMIC PROCESS OPERATION SIMULATION, CURRENT LAB PRACTICALS ARE SUFFICIENT	NO, THERE IS NO NEED FOR A LINK BETWEEN THEORY AND LAB PRACTICALS	I AM INDIFFERENT	YES, A HANDS-ON, MINDS-ON SOFTWARE WOULD BE USEFUL	YES, THIS SOFTWARE IS ESSENTIAL. THERE IS LACK OF CLARITY BETWEEN LAB PRACTICALS AND THEORY CLASSES	TOTAL	WEIGHTED AVERAGE
☆	0.00% 0	0.00% 0	3.23% 1	83.87% 26	12.90% 4	31	4.10

Q6

Export

Please identify the areas of your degree course that use of this software would best suit? (In order of preference, please give module name/brief description)

Answered: 25 Skipped: 6

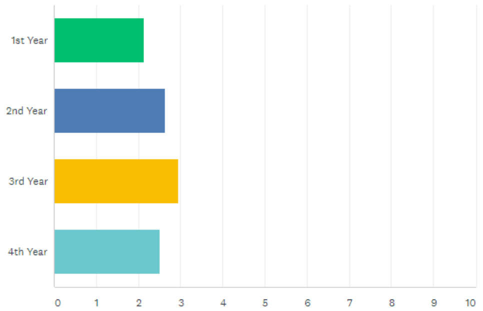
ANSWER CHOICES		RESPONSES	
1.	Responses	100.00%	25
2.	Responses	52.00%	13
3.	Responses	44.00%	11

Q7

Customize Export

In what year of your degree would benefit from the use of Dynamic Process Operations Simulation? (please rank, 1= the best year)

Answered: 29 Skipped: 2



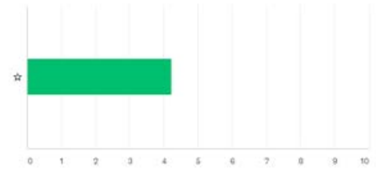
	1	2	3	4	TOTAL	SCORE
1st Year	21.43% 6	21.43% 6	7.14% 2	50.00% 14	28	2.14
2nd Year	24.00% 6	24.00% 6	44.00% 11	8.00% 2	25	2.64
3rd Year	36.00% 9	24.00% 6	40.00% 10	0.00% 0	25	2.96
4th Year	28.00% 7	28.00% 7	12.00% 3	32.00% 8	25	2.52

Q8

Customize Export

Do you think DOS would also be of benefit in the years after graduating? (graduate programs, industry training)

Answered: 31 Skipped: 0



	STRONGLY DISAGREE	(NO LABEL)	INDIFFERENT	(NO LABEL)	STRONGLY AGREE	TOTAL	WEIGHTED AVERAGE
☆	0.00% 0	0.00% 0	16.13% 5	45.16% 14	38.71% 12	31	4.23

Comments (12)

Q9

Export

In general, what areas of your degree are your: most favorite, least favorite and requires modern development? (e.g. unit ops, mass/energy balances, safety, environment etc...). Please give a brief explanation why.

Answered: 22 Skipped: 9

ANSWER CHOICES		RESPONSES	
Favorite:	Responses	90.91%	20
Least Favorite:	Responses	90.91%	20
Requires Development:	Responses	68.18%	15

Q10

Export

Any additional comments would be really appreciated to gain an understanding of student feedback. e.g. what you like/dislike about the software, is it user friendly, do you think it is a waste of time? etc.

Answered: 14 Skipped: 17

APPENDIX E – SURVEY TO GRADUATE PCE ENGINEER

1. What type of 3rd level institute did you attend?
   - University
   - Institute of Technology
   - Other (please specify)

2. How many years since you graduated with a Process and Chemical Engineering degree?
   - 0-2 yrs
   - 2-5 yrs
   - 5+ yrs

3. In what area do you currently work?
   - Safety
   - Quality
   - Control/Automation
   - Process Specialist
   - Design/Optimisation
   - Other

   Please specify your title and elaborate on your job role i.e. daily tasks/responsibilities

4. What area of the Process and Chemical curriculum best prepared you for work? (please select all that apply)
   - Laboratory Practicals
   - Research/Design Projects
   - Theory Classes
   - None of the Above
   - Please elaborate

5. In your opinion, what can be improved and/or introduced into the curriculum to best prepare students entering the work force?

6. Was Simulation Software (e.g. Dynochem, Aspen, SuperPro) used in the curriculum at college?
   - Yes
   - No

   If yes, please state what software and what it was used for

7. Do you use simulation software as part of you role?

- ◯ Yes
- ◯ No

If yes, please state what software and what you use it for

8. How often do you need to communicate with operations staff?

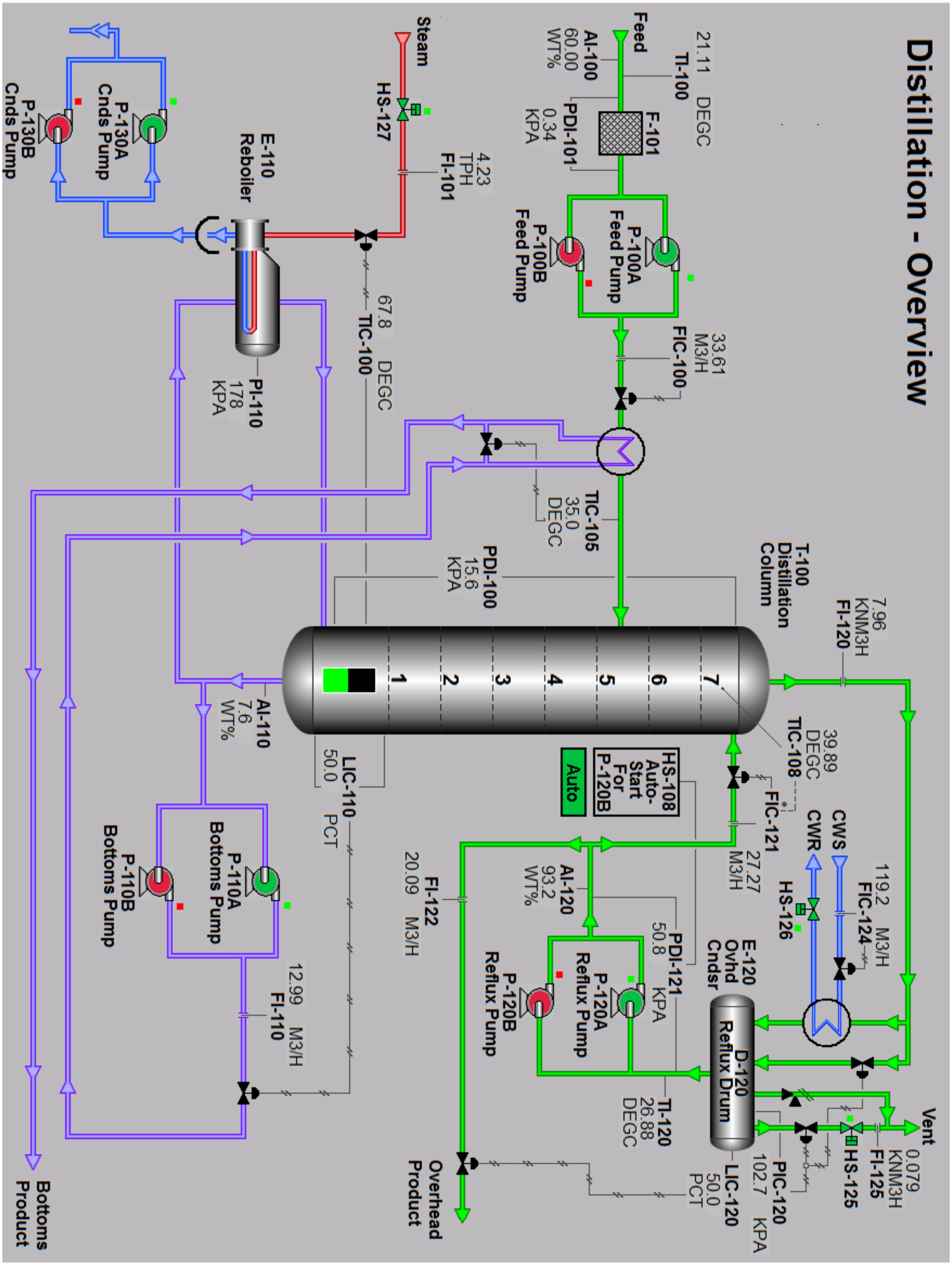
Never	Rarely	Monthly	Weekly	Daily
☆	☆	☆	☆	☆

Please expand

9. Process Operations and Situational Awareness training is just as useful for Process Engineers as well as operational staff?

Strongly Disagree		Indifferent		Strongly Agree
☆	☆	☆	☆	☆

APPENDIX F –SIMULATIONS SOLUTIONS INC. DCS INTERFACE



APPENDIX G – SIMULATION SOLUTIONS INC. DISTILLATION TOWER P&ID