EXPERIENTIAL LEARNING USING A COMPUTER-BASED VIRTUAL RECONSTRUCTION OF AN ACCIDENT INVESTIGATION.

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Abstract: This paper describes the development of an interactive computer-based laboratory exercise for first year engineering students, in which they take the role of an accident investigation team sorting through information and analysing evidence. The accident the students investigate is based on the actual collapse of a passenger walkway at the Port of Ramsgate in 1994, which was investigated by the Health and Safety Executive (HSE) with forensic support from the Health and Safety Laboratory (HSL). The exercise was initially paper-based using the photos and witness statements taken during the actual investigation, original design drawings, a metallurgical analysis by HSL, and the wooden scaled models of the accident scene and failed component that were built by HSL for use in the court prosecution of those found ultimately responsible.

Feedback from students informed the design of a computer-based version. For example, some of the more difficult underlying engineering principles are animated. A large amount of information is organised and presented so as to engage students and help them make sense of what happened and the underlying responsibilities. The new computer-based version has been used at the University of Liverpool since 2010. Removing the dependence on the wooden model also means that other universities could potentially use it, and the authors are keen to explore how this could be achieved.

The active experiential nature of the real-life scenario and role-playing helped students to consider the wider implications of their activities as professional engineers in society. The exercise also encouraged team working, verbal communication, and literacy.

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Keywords: Experiential, virtual reconstruction, accident investigation, risk management.

1. INTRODUCTION

Experience may be the best teacher but, when it comes to industrial accidents the price can simply be too high to pay, as illustrated in Figure 1. The long history of engineering has left a rich and varied collection of examples of mistakes and catastrophic failures. The challenge
therefore, is for student engineers to learn through their mistakes and those of others without endangering anyone’s health and safety including their own. It is obviously neither practical nor realistic in terms of timing or safety to take a group of students to an accident scene.

![Figure 1: The price of mistakes](image)

However, it is possible to bring the accident scene to them through a computer-based virtual reconstruction. The one described in this paper is designed to be used as a three hour laboratory exercise and allow first year students to learn from the mistakes of others in a way that is active, experiential and engaging. It was developed, first as a paper-based exercise, during a wider collaborative project between the Health and Safety Executive (HSE), the Health and Safety Laboratory (HSL) and the University of Liverpool. The goal of this project was to ensure that all students who complete their engineering course\(^1\) at the University of Liverpool have a basic understanding of safety and health risk issues relevant to their specific course of study. To this end, a set of learning outcomes (Schleyer et al, 2005) that could be embedded into an undergraduate engineering curriculum were developed (taking into account the other demands placed upon it). A variety of new materials were also integrated into a selection of core engineering modules (Stacey et al, 2009) of which this exercise was one. The learning outcomes and associated resources were designed to meet the requirements of the engineering council (EC, 2004), and were underpinned by their guidance for engineers on risk issues, current at the time (EC, 1993) but which has since been revised (EC, 2011). Other resources developed and identified during the overall project can be obtained via the Risk Education Network (Stacey and Bowen, 2012).

**2. THE ACCIDENT UPON WHICH THE EXERCISE IS BASED**

Just before 1 am on 14\(^{th}\) September 1994 at the Port of Ramsgate, one end of a walkway, used by foot passengers to embark onto cross-channel ferries, fell 10 metres causing the death of six passengers and severe multiple injuries to seven others. The walkway had only been in service

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\(^1\) As taught by the engineering school, i.e. Mechanical, Civil, Structural, General and Aerospace
for four months. Investigating HSE inspectors quickly found that the immediate cause was the failure of the weld securing the end of the right-hand seaward stub axle to the walkway. Furthermore, a review of the design revealed that it did not provide the support and articulation necessary, did not allow for the roll of the pontoon caused by the movement of the sea beneath, and that design calculations of the loadings were inadequate. The report of HSE’s investigation into the collapse of the walkway (HSE, 2000), from which the above extracts are drawn, concluded that it was “caused by a series of errors in the design; some of which were gross” and that “these were compounded by defective fabrication work and a lack of adequate maintenance procedures”. Moreover that “all these resulted from the absence of organised project management”. The port operator, the designer, the main fabrication contractor and the classification society were all prosecuted and convicted with fines totalling £1.7 million and costs of £0.7 million being awarded to HSE.

3. THE PAPER-BASED EXERCISE

3.1 Description

As explained by Schleyer et al (2008), traditional undergraduate engineering laboratory exercises have mostly been designed to verify specific theoretical concepts that have been delivered during formal lectures. Schleyer goes on to explain that this type of laboratory practice is characterized by a set of sequential instructions given to students on how to apply specified laboratory equipment and to observe expected phenomena under specified conditions. Professional engineering though is about problem structuring and solving, applying theoretical knowledge in the conception, design, implementation and operation of new products, systems, processes and services. Moreover, technical knowledge and skills need to be complemented by sound appreciation of the ethical, health, safety, environmental, economic and social considerations involved in practicing as a professional engineer. The accident investigation exercise described here was linked to a taught module on mechanics of solids, which introduced various key concepts relevant to the accident. However, in contrast to a traditional engineering laboratory, students explore information and evidence in a (relatively unstructured) way to find answers to what happened, how and why.

The development of this laboratory exercise drew upon lectures and exercises developed some time previously by HSL with the University of Sheffield engineering department. It can be delivered in a single 3-hour ‘jig-saw’ learning session (whereby students each seek out different information and report back to the rest) or as a series of five 3-hour sessions, each of which builds upon the findings of the previous one. Professor Taylor (chair of the Inter-Institutional Group on Health and Safety) also prepared a role-play exercise to complement the engineering aspects by looking at the underlying organisational and cultural issues in more detail. This involves students representing the different organisations, describing what they would have done differently and how they believe this would have prevented the collapse.

Students take the role of an accident investigation team sorting through information about the accident and have to share out specified tasks, as described in worksheets, which look at the accident from different perspectives (design appraisal, stress analysis, operational risk management, and metallurgical inspection). Based on their analysis of the available evidence, students present their finding to the rest of the group and are encouraged to question and discuss the findings of the others. After the exercise, they each write short individual ‘expert witness’
statements about the accident, including their opinions about the root causes, why the accident happened and who was responsible. Marks are awarded to students based on the worksheets completed as a group during the session and also for their individual statement, which is handed in later.

To provide the students with a complete view of the accident scene along with a series of clues to how the accident occurred, the wooden 1/100th scale model of the Ramsgate ferry terminal showing the failed passenger walkway (as used in the court case), was on display, as well as a full-scale physical model of the critical structural component, the failure of which was the immediate cause of the accident. Folders are also provided containing background information about Port Ramsgate, the design drawings and calculations, notes about the fabrication of the walkway, a record of various operational problems, witness statements and photos taken from the scene.

3.2 Role of the laboratory demonstrator
The laboratory demonstrator’s role is vital (Schleyer et al, 2008). They facilitate the exercise so as to give the students the best chance of successfully completing the exercise by: getting them to work as a team, ensuring that they understand what they need to do, encouraging them to search for clues, making sure they do not get overwhelmed with information, and guiding them if they stray too far in the wrong direction. A good lab demonstrator knows when to step back to give students time to think things through for themselves and when to intervene to give them a nudge in the right direction. They also need to spot when the group is not working as a team, be able to encourage participation by asking questions, and stimulate discussion. Several fun ice-breakers were also developed for the purpose of getting the students into the right frame of mind, thinking about risk and talking to one another at the beginning.

3.3 Evaluation
The exercise succeeded in encouraging team working and gave an opportunity to practice presentation skills. The exercise also raised the profile, within the school of engineering, of health and safety risk integration in engineering education and was accepted by staff as a valuable learning experience. Students learnt for example (Schleyer et al, 2008) that:

- There were justifiable safety reasons for introducing the passenger walkway, some risks were reduced (by separating foot passengers from car traffic, protecting them from the weather), and others were increased by the new design.
- Failure of any one of the support feet could have led to a catastrophic collapse. These were, therefore, safety critical components for which a high safety factor should have been used and/or a back-up mechanism provided to protect against a dangerous collapse if they failed. The design should also have allowed for ease of inspection and maintenance of these components.
- The designer and the fabricator made a series of gross errors in carrying out their work for which there were adequate standards and guidance and for which the court held them accountable.
- Failure of the walkway could have been avoided if the operators, Port Ramsgate, had responded to defects that became apparent during operation.
- The main load points on the walkway would come under additional stress due to the rolling action of the pontoon, assumptions for the load path and static analysis were
therefore unrealistic and incorrect resulting in a design that led to unacceptably high stresses in the critical component.

- Fatigue cracking is a critical failure mode due to dynamic loads and environmental factors.
- Effective project management, understanding of the risks, quality assurance and monitoring procedures are essential for design projects of this nature.

Feedback from students indicated that, on the whole, they enjoyed the exercise and that it helped them to consider the wider implications of their activities as professional engineers. A questionnaire survey (Underwood 2008) involving 52 students found that the majority (92%) of the students felt that the exercise improved their perception of risk and/or awareness of their responsibilities. However over half of the students (53%) felt that the there was insufficient time to carry out the exercise, and an appreciable number (27%), found it difficult to visualise the structural components, or identify the causes of the accident.

Observations of students during the paper-based laboratory exercise indicated that completion of the entire tasks within the allotted time required that the students: worked effectively together as a team, communicated, and cooperated well with each other. It was also important that students quickly found and understood the information relating to the accident and the underlying design. Moreover, they needed to be able to reflect on the relevance of different pieces of information and how they related to one another was also important. Not all the students were able do this and some were overwhelmed by the quantity of information.

4. DEVELOPMENT OF A COMPUTER-BASED VERSION

4.1 Background
The primary reasons for developing a computer-based version of the accident investigation laboratory were to: improve the student experience; allow more flexibility in how, where and when the exercise is run; and to potentially make it easier for other universities to use it. When students were surveyed (Underwood, 2008) about the paper-based exercise, the majority (94%) also said that they thought a virtual reality reconstruction of the accident scene would be useful with over half (57%) saying it would be very useful. It was, therefore, decided to simulate the accident scene on a computer, embedding all the information (previously held in the folders) that the student needed such that the student could retrieve it by interacting with the simulation. However, for convenience it was decided to keep the worksheets and instructions separate and essentially paper-based.

4.2 Steps in the creation of the virtual reconstruction
The first step was to produce a basic computer model of the Port of Ramsgate roll on/off ferry terminal including the walkway that collapsed, the double-deck floating pontoon, the two vehicle access bridges, and the immediate environment. The existing wooden model, original design drawings for the walkway, and measurements taken during the investigation were used to create an accurate representation. The surrounding environment, terminal building, offices and the sea were then rendered with photographic bitmaps to provide realism as shown in Figure 2 below.

The second step was to animate those parts of the model that would best help students visualise the key engineering principles that were pertinent to why the passenger walkway collapsed.
These were the foot assembly, the failure of which was the immediate cause of the accident, and the pontoon to show the six possible degrees of freedom (heave, sway, surge, pitch, yaw, and roll). The animation of the foot assembly was such that it exploded to reveal all the component parts, labelling them and showing how they fit together.

![Figure 2: Screen shot of 3D computer model of Ramsgate walkway](image)

The third step was to produce storyboards to explain how the user should interact with the simulation and how it would respond in order to achieve the objectives of the exercise. Each storyboard depicted exactly the information to be included in the final simulation, where it would sit and how it would be found. They were carefully designed to ensure the students are driving the search for data and are not just been guided through the facts to be able to complete their worksheets. An introductory presentation was also produced that the students could watch at their own pace before beginning the exercise to set the scene, explain what had happened and in general what they were expected to do.

The fourth step was to produce a user interface that seamlessly combined all the different elements and allows the user to interact with them. At this point, a decision had to be made as to whether to simulate the accident scene as an immersive virtual reality (VR) environment or as an interactive graphic where the student could see the overall scene and zoom in on different aspects in turn. The latter was chosen mainly because trials with students of the 3D VR model found that students tended to get lost, were unable to understand the overall situation, and took a long time to find the necessary information. Other factors taken into consideration were the cost and processing power needed to create a sufficiently high quality interactive VR system.

4.3 Computer tools used

A modelling package called 3D Studio Max was used to create and animate the models due to its ability to create realistic rendering of the model and place it in a realistic background environment. ADOBE interactive flash software was used to combine all the different elements into the final simulation. The interactive graphical user interface was coded using Action Script 2. Events were set on a time line with different scenes of interest along the time line reachable by clicking on the associated button.
5. RESULTS

The computer-based version of the accident investigation exercise using the simulated accident scene was fully integrated into an undergraduate laboratory at the University of Liverpool in March 2010 and has since then been used each year to successfully deliver an enriched experience for the students with the same learning outcomes as the paper-based version. All the information the students need, including an introductory presentation to set the scene, explain what had happened and in general what students are expected to do, was successfully embedded in different parts of the simulation. For example design drawings, a diary of key dates, correspondence between the different organisations, a maintenance log and analyses conducted by the accident investigators are located on the shelves, on the desk and wall in a simulated office building. Various witnesses are located around the site, who when selected provide statements as to what they saw or did. These give graphic details of the damage and injuries caused by the accident to help emphasise the severity of the accident but also sometimes give clues as to where to look for more information. The safety critical component is modelled in detail and the six degrees of freedom of the floating pontoon are animated. The simulation allows students to study different aspects at their own pace, in an order of their own choosing, returning to them as necessary including the introductory presentation. The full-size model of the failed part was retained in the exercise as this gives students a sense of scale. The school of engineering has made two new full-size models of the failed part, which now enables more students to take the lab over less weeks and helps to improve synchronising the lab with lecture material. An experienced demonstrator can therefore work with two groups of students at the same time.

Feedback from students has been very positive; the majority stating that they found it engaging and easy to follow. Observations of how they used the package and what aspects they continued to find difficult, along with their suggestions, has led to a number of refinements and enhancements, including the demand for more information to be embedded. For example the latest version embeds a stress analysis model of the critical foot assembly that failed, showing how the stresses change with the movement of the pontoon.

6. CONCLUSIONS

The computer-based version of the accident investigation laboratory exercise provides an enriched student-centred, active experiential learning experience. It demonstrates that by engaging the students and allowing them to interact with a simulation helps them organise and reflect on a complex set of information and in so doing learn a variety of valuable lessons associated with the wider implications of their activities as professional engineers in society.

The embedded introductory presentation helps the students get started quickly so that they don’t become disengaged. It also ensures consistency between groups and that all students begin with the same basic level of understanding.

The animations enabled students to better understand how the supported ends of the walkway and safety critical foot support moved in relation to the degrees of freedom of the pontoon. By putting the students in control of how long they spend considering the different aspects of the simulation a range of abilities are catered for. Every student is able to access the computer simulation during the exercise and also afterwards if they need to check on any details when
writing their individual ‘expert witness’ statement. The way that information is dispersed through the simulation avoids students from becoming overwhelmed by the quantity of information; they complained that there was too much in the paper exercise but too little in the simulation, even though there was in fact more.

The paper-based worksheets are important for giving the exercise structure, making sure that students have clear tasks to complete so that they do not simply ‘play’ with the simulation. They also ensure that the exercise still encourages team-working by giving students different tasks to do and requiring them to feed back their findings to the rest of the group. Keeping the worksheets that specify the tasks separate from the simulation, which provides the information also allows the exercise to be changed and kept fresh.

Removing the need to display the wooden model or use folders of information makes running the exercise more efficient and convenient. It also means that other universities could potentially use the exercise at relatively low financial cost. The worksheets being independent of the simulation and essentially paper-based mean that they can be adjusted according to the needs of different universities, for example as self-study mini-exercises, to accommodate a different session duration or group size.

7. REFERENCES


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