INTEGRATING RISK CONCEPTS INTO UNDERGRADUATE ENGINEERING COURSES

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Abstract
The health and safety agenda is becoming increasingly important in engineering education as employers expect graduate engineers to be risk aware and have an appreciation of their professional responsibility for their own safety and the safety of others. This paper explains the importance of engineers graduating with an understanding of health and safety risk concepts. It describes various approaches to, and the development of materials for, the teaching of risk concepts through an integrated approach within an undergraduate mechanical engineering degree and an e-learning package. Results are also given of an assessment of students' understanding of risk concepts.

Keywords: health and safety risk, development of teaching material, professional engineers' responsibilities and codes of conduct

Introduction
Engineers play a vital role in managing risks, including those relating to health and safety. It is therefore essential that engineering graduates are prepared for that role. For some time there has been recognition, in the UK by the Health and Safety Executive (HSE) [1], other UK government offices [2], professional bodies and institutions [3], [4], [5] of the need to educate engineering undergraduates in aspects of risk relevant to their degree and future professional working life.

The EU strategy on health and safety also identifies education and training as key factors to prevent accidents among young people when they first enter the workplace. An EU project to mainstream occupational health and safety into education [6] was started in 2002. Following on from this a European Network for Education and Training in Occupational Safety and Heath was established "to facilitate the distribution and use of good practice of mainstreaming occupational safety and health into education and training". Furthermore, the focus of the main Health and Safety campaign in Europe for 2006 was improving the health and safety of young workers, known as 'SafeStart'. Fundamental to the campaign was the recognition of the importance of education and training to ensure a young person's *safe start* in employment [7]. Many of the good practice awards were given to those developing educational resources for use in schools or vocational training [8].

Despite this, across degree courses in the UK, there is evidence that the extent and content of risk education varies, and there is potential for it to not always be proportional to the level of risk that undergraduates could be responsible for managing in their professional working life [9]. To address this, HSE have commissioned two projects. One, a joint project of the Health and Safety Laboratory (HSL) and the University of Liverpool, is to incorporate risk education into the curriculum of an undergraduate engineering degree course [9]. The other (being led by the chair of the UK engineering institutions Inter-Institutional Group on Health and Safety with the assistance of HSL) is to develop an e-learning package [11] that can be used flexibly in support of engineering degree courses or employers' graduate training programmes.

The overall goal of both projects is to ensure that all students who complete their engineering course have a basic understanding of safety and health risk issues relevant to their specific course of professional study. The Universities Health and Safety Association (USHA) intend, this year, to issue a questionnaire to universities to establish whether the extent of teaching of health and safety has increased.

Integrating health and safety risk into the curriculum has involved defining risk education as a set of learning outcomes, and designing a tool to ascertain students' awareness of risk issues and key concepts. Teaching materials have been developed for these learning outcomes that use real accident case studies, student interaction and role-play exercises to enhance students' understanding of the concepts of hazard and risk.

Learning outcomes

The two projects described in this paper both took as their starting point a template categorizing risk learning outcomes [12] that was originally developed by the Inter-Institutional Group (IIG) on Health and Safety. This influential group is composed of senior representatives from the main engineering institutions in the UK, plus the Hazards Forum and the HSE. Drawing upon other relevant work in the field of risk education, a proposed set of risk education topic areas was developed for undergraduates. These were grounded on current professional requirements of the engineering institutions, legislation, and best practice described in relevant HSE publications and current academic courses. These topics were circulated in consultation to a limited number of key stakeholders in HSE, academia and the engineering institutions, to obtain their opinion and produce a final set of risk education topic areas and associated learning outcomes.

Embedding in an undergraduate engineering course

The learning outcomes, given below, are a sub-set derived from [12] so as to balance the necessary knowledge of risk concepts for graduate engineers on entering the professional arena with the competing demands of other new topics on the curriculum, such as sustainability. They incorporate those areas that were identified during the consultation as high priority e.g. personal safety and the importance of using appropriate design standards.

On graduation students should be able to demonstrate *knowledge and understanding* of:

1. Concepts of hazard, safety and risk as part of everyday life.
2. An engineer's professional responsibilities for safety and managing risk.
3. Principles of hazard identification and risk assessment relevant to the discipline.
4. Methods of hazard identification and risk assessment relevant to the discipline.

5. Techniques for reducing and controlling risk.
6. Personal safety and potential exposure to hazards and risk in the workplace.
7. Underlying causes of accidents and failures.

On graduation, students should be able to demonstrate *ability in applying knowledge* of the topics to:
1. Design simple engineering systems for safety accounting for uncertainties.
2. Perform a risk assessment using appropriate methods, avoiding some of the common pitfalls, and implement, where necessary, effective risk reduction measures.
3. Learn from documented failures and accidents the underlying hazard, safety and risk issues and relate this knowledge to their future professional responsibilities.
4. Identify and control safety hazards to themselves and others in the course of work activities.

Appropriate for an e-learning package

A more comprehensive list of learning outcomes, incorporating all those given above, has been drawn up for the e-learning package [13]. This is possible on the basis that the package will be used semi-independently by students who are not necessarily required to complete all sections. Moreover, the final product will be modular so that universities can select only those sections that are relevant to the engineering courses it is used to support.

In line with the original template [12] of the IIG on health and safety, the list of learning outcomes has been categorized according to the following four levels of student capability:

A	**A**ppreciation and awareness: be able to refer to something
K	**K**nowledge and understanding: be able to explain something
E	**E**xperience: be able to do something with help and/or closely supervised
B	A**B**ility : be able to do something without supervision

Evaluation of student awareness of risk

A questionnaire was developed to ascertain students' base level of understanding of the risk education learning outcomes prior to receiving formal tuition at undergraduate level. Therefore, the questions were designed to assess understanding and awareness of concepts as opposed to knowledge of facts relating to a taught course. The project team first agreed the key concepts for each learning outcome. This questionnaire enabled the researchers to gauge the impact of the risk education learning materials through comparison of the results from two cohorts of students, one of which had not received the risk education material integrated into their course.

A total of fifty multiple-choice questions were developed to provide an indication of students' knowledge and understanding in the following topic areas:
1. Concepts of hazard, safety and risk as part of everyday life (12 questions),
2. Engineer's professional responsibilities (12 questions),
3. Principles of hazard identification and risk assessment (8 questions),
4. Techniques for reducing and controlling risk (6 questions),
5. Potential exposure to hazards and risk in the workplace (6 questions), and
6. Underlying causes of accidents and failures (6 questions).

Due to the time constraints there was no formal testing of the validity of the questionnaire, though there was a limited piloting, resulting in non-substantial changes. The face validity of the questionnaire was judged to be appropriate according to the experience and knowledge of the project team.

A multiple-choice style of question format was adopted to reduce the subjective element of marking a large number of open-ended answers, and to better facilitate comparisons between levels of understanding across the various risk topic areas. Each question had a possible five answers from which the student had to mark one choice that was in their opinion the best or correct answer. A few questions had a number of potentially valid answers, though the 'correct' answers were based on the preferred set of responses defined by the project team.

A cohort of new entrants completed this questionnaire at the start, and the end of the 2004/05 academic year. There was a small overall improvement in their scores at the end of the year that was statistically significant. When these end-of-year scores were compared with students' overall end-of-year examination scores, there was found to be no relationship. This suggests that any improvement in scores between the risk questionnaire at the start, and end of the year, was due to practice effects, and a general learning effect.

The questionnaire was also delivered to the new 2005/06 students, who were taught using the new materials on health and safety risk concepts, via the on-line virtual interactive teaching and learning system at Liverpool. The format of the questions was unaltered.

A comparison between the average scores in each section of the questionnaire for the 2004/5 and 2005/6 cohorts at the beginning of the academic year (after the first lecture) is given in Figure 1. This shows consistency from year to year across the range of topics. The data from these tests allowed specific areas to be targeted in which the students performed less well than expected or showed a lack of appreciation in a particular topic as highlighted by a poorly scoring question. It was reassuring to know that the topic that students appreciated the most was personal safety in the workplace, which was highlighted as a priority in the consultation exercise. On the other hand, accident causation was the least well understood.

A T-test was conducted to compare 2004/5 scores with 2005/6 scores at the beginning of the academic year. This gave a very high correlation of the scores (0.98), at a 95% confidence level. Thus it is 95% certain that the difference between the groups' scores is not due to chance. This gives a strong basis for proceeding with using the class test to evaluate the success of the new syllabus in achieving the desired learning outcomes relating to risk concepts.

The 2005/06 students, who were taught using the new materials on health and safety risk concepts, performed significantly better at the end of their first year than the previous students who were not exposed to the new materials. A comparison of the percentage differences between the median scores is shown in Figure 2.

In addition to the 50 multiple-choice questions in the 2004/05 evaluation, an open question was set at the end. The students were asked to convey why engineering is regarded as a safety critical profession. Most recognized that faulty products put the public at risk of injury or death and that as engineers they therefore had a responsibility to ensure safety was properly considered during design. Many recognized that engineering decisions have a wide impact on everyone. The most succinct answer was: “People count on engineers to deliver”. Only a few mentioned their responsibility for their own safety and that of their colleagues. However in the 2005/6 cohort over half of the students mentioned personal safety.

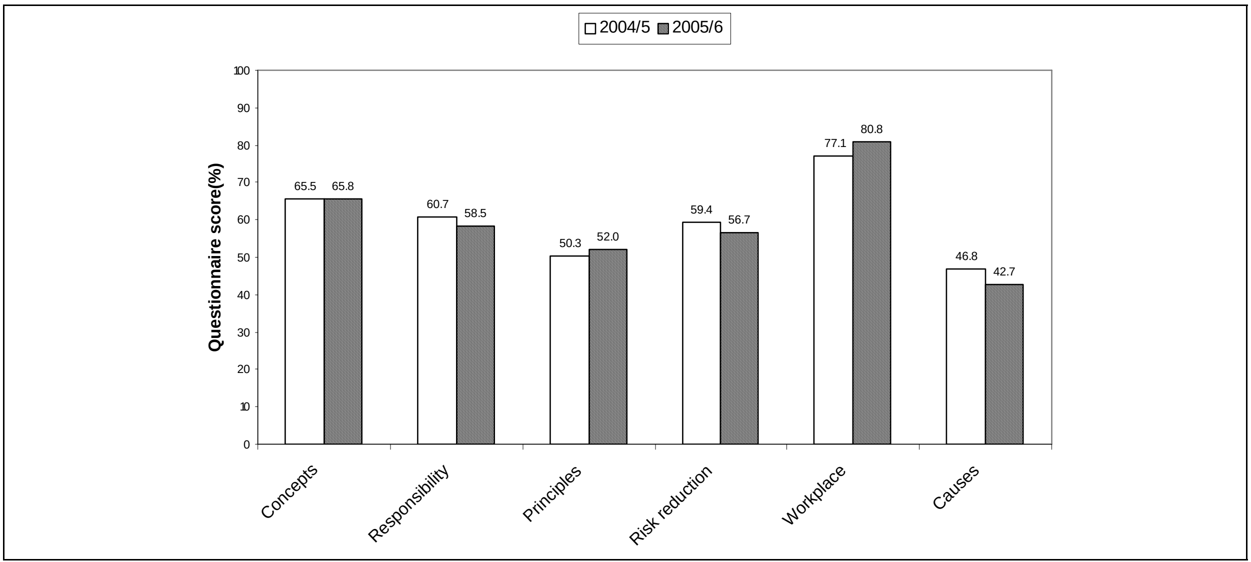

Figure 1. Comparison of average scores by section

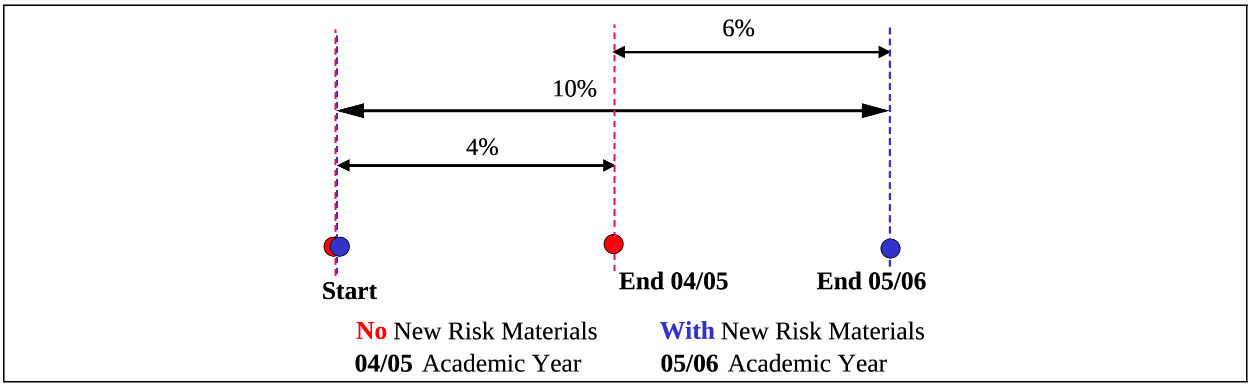

Figure 2. Comparison of median scores

Health and Safety Risk Syllabus at the University of Liverpool

Background

The engineering taught programmes at the University of Liverpool are aimed at developing to Honours degree level the knowledge, skills and understanding of their graduates to meet the needs of industry. The mechanical engineering taught programme (which is typical of the engineering taught programmes at Liverpool) aims to provide graduates with a sound understanding of engineering principles and the ability to undertake teamwork and communicate ideas. Graduates should also understand the engineer's role within industry in the UK and Europe.

The 4-year MEng programme provides a greater depth of understanding through specialist options and opportunities to develop innovation and leadership skills through group design work and an enhanced project. The course is designed to meet the full MEng requirements defined by the UK Standard for Professional Engineering Competence (UK-SPEC) [14]. The programme's aims, which go beyond those of the 3-year BEng programmes given above, are:

- To develop the students' academic knowledge in certain engineering topics to an advanced level beyond that of the final-year BEng level;
- To develop further knowledge and understanding of aspects of management of the technical function; and
- To develop further knowledge and understanding of European matters relevant to engineers, or to develop language skills.

Risk topics have been successfully embedded into first and second year core engineering modules, through formal lectures, a virtual accident investigation laboratory exercise and lectures on professional practice by visiting experts on key health and safety risk themes. The lectures and laboratory exercises are complementary, with the laboratory exercises promoting learning through experiential role-play.

It is expected that by embedding risk education into the programmes in this way engineering students will graduate with:

- An understanding, as professional engineers carrying out their own activities, of their responsibility for the safety of others.
- An understanding of safety and risk issues relevant to their own specific discipline.

New materials

New materials have been developed for delivery by various staff in different contexts and modules.

A few additional slides were developed for incorporation into the laboratory safety talk given to first year students. The purpose was to get over key messages about personal safety and every individual's responsibility under UK health and safety law.

Some slides and video clips were provided for the Head of Department's introductory lecture, to first year students, to enable him to put the engineering programme the students are about to follow into a health and safety context.

While retaining the engineering science theme, several of the key risk concepts are delivered by linking them to stress analysis through case studies of engineering disasters in an engineering mechanics module. The case studies are used to show what can happen when engineers get it wrong, make mistakes, or even worse, ignore the warning signs that something is wrong. Two BBC Disaster Series films, the Challenger Space Shuttle and Piper Alpha, are being used in the lectures as showcase examples of how wrong decisions can lead to disaster. This encourages students to think outside the confines of theory, to real issues that could affect them in their future professional life. Safety issues are embedded in the lecture material and integrated with the theory rather than added on as a separate topic. New PowerPoint slides have been produced to enhance the presentation and enable the material to be reviewed on the University's virtual interactive teaching and learning (VITAL) system.

Virtual laboratory

A new virtual laboratory exercise has been designed based on HSE and HSL's investigation into the collapse of a passenger link bridge at the Ferry Port in Ramsgate [15]. The development drew upon a similar exercise run by the University of Sheffield. The aim of this laboratory is to learn about the accident investigation process and to appreciate the important lessons that can be drawn from engineering failures, including that accidents generally have no single cause.

A re-construction of the scene has been created with a 1/100th scale model that was used in the actual court prosecution and a file of data comprising photographs, witness statements and other technical documents, mainly taken from the accident investigation report. All first year students take the laboratory exercise in small tutor groups of around 6 to 10 students that take on the role of an accident investigation team. In order to get through the set tasks, they need to share out the work and brief the rest of the team of their findings. These tasks include: gathering evidence; consideration of the design concept; implementation and operation, including stress analysis; and risk assessment. Initial indications are that students are engaged with the material and working together as a team. Some groups need a bit more encouragement to interact as a team than others. This is where the role of the demonstrator is important to the success of the laboratory. The new laboratory is generating considerable interest among staff and is becoming accepted as an important element of the student's active learning experience.

At the start of the session students are given a tongue-in-cheek icebreaker to get them thinking and talking to one another. If the group appears to be rather quiet then the laboratory demonstrator uses the icebreaker questions to generate discussion. The laboratory proper then commences with a short introductory talk either from a member of staff or a competent research student (the demonstrator). Thereafter the students will follow the instructions of the demonstrator who is there all the way through to facilitate the students, but not to do the tasks for the students. Students are encouraged to search for clues on the model and follow them up using the file of information, and then to present and discuss their findings using white boards and mind-maps. A worksheet has been prepared to guide the students through the tasks and lead them to record the important information so that they can write an expert witness report to be handed in the following day.

New keynote lectures on professional practice

A number of experts have given keynote lectures, as part of first and second year core design modules, on the following topics:

- Professional responsibilities
- Human factors
- Inherent safety
- Use of codes and standards
- Risk assessment of technical systems
- Risk reduction measures

Additional multiple-choice questions have been provided by the experts to test students' understanding of the content of these lectures.

Final year projects

In their third, and for MEng fourth, year students will be expected to put what they have learned into practice as part of their final year project. Additional requirements and guidance material is being developed on the risk management aspects. Tutorials are planned where visiting experts will be available to assist the students.

In addition, a number of final year projects have been set up to develop the use of real-world accident data to reconstruct the events leading to the accident and determine the causal factors. For example one has looked at the effects of flight into a severe wind shear caused by microburst and another following a failure of the rudder actuator. Both are based on real-world accidents. It is planned to make more use of these types of forensic investigation projects in the future. Another final year project has been used to explore the use of a machinery safeguarding demonstrator unit as part of a laboratory exercise or lecture demonstration. This project draws upon the demonstrator used by HSL to train HSE inspectors to recognize operator interference with machinery safeguards.

At the end of the year the intention is for the key messages about the management of risk, including in relation to health and safety, to be reinforced by the Head of Department just before students take their final exams or during his graduation speech.

Development of an e-learning demonstration CD

Three "layers" of material are proposed for an interactive e-learning package for use by students semi-independently as part of an engineering undergraduate course or graduate training programme. The first will be a simulation, using interactive video or virtual reality, of a team of three young engineers undertaking a range of projects as part of their graduate training with a major company. In carrying out these projects, they address and discuss the identified issues. The second "layer" will consist of briefing material, interactive tutorial exercises and assessments to reinforce the concepts covered in the simulations. The third "layer", will be accessible from the same user interface, but would be populated by university departments to meet their specific needs.

As examples, the first part of the journey might involve the team flying to an oil platform in the North Sea where they would help to undertake safety assessments. Students would be introduced to terminology such as the difference between hazard and risk and how to achieve the balance between safety and costs. The second project could involve their assistance in identifying and remediation of health and safety risks on a newly acquired construction site. This would involve a hazard spot, and an understanding of how to control and reduce risks in accordance with legal requirements. In the third part of the "journey", the team might be "loaned" to a developing country to contribute to both the technical aspects and management of a community project, perhaps renewable energy, supply of clean water, or an innovative transport solution. Finally, they might be involved or help to investigate a complex, major, "organizational" accident at one of the company's sites, thus introducing issues relating to safety by design, organization for safety, human factors and safety culture. The intention of the simulated projects is that they should not be overly concerned with engineering detail, but should be sufficiently broad to be of interest to all engineering disciplines. They should be challenging to capable students but not too daunting for less able students.

In each of these simulations, the team will encounter health and safety issues, debate them and, as a result, questions and issues are raised for the student to think about and address. The briefing materials and interactive tutorials will support this process at appropriate points in their simulated journey. Alternatively, the briefing materials and tutorials can be used as standalone exercises. The package will be able to be run in self-assessment mode to provide automatic feedback or supervised mode so that students submit their work to a tutor who then provides feedback. The package would be designed to be modular and used in the form of a “toolkit”. Learning outcomes will be explicitly linked to the different modules so that university departments can tailor the journey to support project or course work, rather than be a specific extra part of the curriculum.

The outline and proposed approach has been discussed with a wide range of stakeholders, including the IIG, Engineering Council (UK), Higher Education Academy (HEA) Engineering Subject Centre, three university departments (including students) and the Engineering Professors’ Council. It has also been discussed with several major industrial companies. In all cases, the overall response has been positive, particularly to the idea of a modular, layered structure and the use of a strongly interactive ‘gaming’ approach. As a result, a demonstration CD has been produced containing a representative sample of the proposed material for further discussion with potential funding organizations and end-users. A copy of this demonstration CD can be obtained from the corresponding author.

The demonstration CD includes eye-catching introductory real-life material including video-clips of personal stories and major disasters. The construction site ‘spot-the-hazard’ project has been developed in an interactive virtual reality environment. Briefing materials and interactive tutorials have been produced covering: the difference between hazard and risk, why people view risk differently, comparison of risks, quantitative and qualitative risk assessment. There is also a presentation of the background to and overall aims of the project, including the full list of learning outcomes.

Summary and concluding comments

Learning outcomes have been specified, in consultation with key stakeholders, that are grounded in current professional requirements of the engineering institutions, legislation, and best practice described in relevant HSE publications and current academic courses. The full list is suitable for a flexible e-learning package that can be tailored, as appropriate, to support university courses or graduate training programmes. A compatible sub-set of outcomes has been extracted that can be embedded into an engineering undergraduate course whilst taking into account the demands of other topics in the curriculum.

A class test in the form of a questionnaire that can be given to students has been shown to be a reliable indicator of students’ awareness of risk concepts. It has been used at the University of

Liverpool to set the appropriate level of tuition and will be used to help evaluate the success of the new syllabus in achieving the desired learning outcomes.

Risk topics have been successfully embedded into core engineering modules at Liverpool through formal lectures by staff and visiting experts, and a virtual laboratory. The lectures and laboratory are complementary, with the laboratory promoting experiential role-play learning.

There is already good anecdotal evidence from the virtual laboratory that students are beginning to seriously consider risk issues. Their answers to the key question set in the risk awareness questionnaire ("why is engineering regarded as a safety critical profession?"), show that engineering students at the University of Liverpool understand to a significant extent their professional responsibilities for the safety of the public as recommended in the recommendations of the Hatfield rail accident investigation board [2].

Clear proposals for the functional specification and content for an e-learning package have been developed and a demonstration CD produced, containing a sample of the material illustrating how the final product could be used.

The projects funded by HSE described in this paper clearly demonstrate that it is possible to develop materials to integrate health and safety risk concepts into engineering courses. Both projects use active learning methods (CDIO Standard 8) in the form of role-play of real-life scenarios to engage students to consider the wider implications of their activities as professional engineers in society (CDIO Standard 7).

All UK Engineering Institutions require chartered engineers to have some knowledge of the issues addressed by this project. The extent to which they are specified in requirements for accredited engineering courses, however, is variable and difficult to interpret or audit. In the opinion of the authors the requirements of UKSPEC [14] are currently insufficient in themselves to provide the impetus for universities to more fully integrate risk concepts into their undergraduate courses.

Acknowledgements
The authors wish to thank the HSE and the University of Liverpool (Studentship Awards) for funding this work. Information and advice received from Brian Fullam of HSE, Paul Davies of the Institution of Engineering and Technology (IET), Patrick McDonald, Chief Scientist of HSE, Paul Davies and Jim McQuaid, former Chief Scientists of HSE, Martin Keay of EnSure, and Liz Williams of the British Standards Institution (BSI), Steve Joel, Graham Norton and David Gregory of HSL, is gratefully acknowledged.

The authors would also like to acknowledge the encouragement and support of all the main engineering institutions of the UK, in particular the Institution of Mechanical Engineering's Safety and Reliability Group (IMechE SRG), Inter-Institutional Group (IIG), Hazards Forum. Also the Safety and Reliability Association (SaRS), Royal Society for Prevention of accidents (RoSPA), Institution of Occupational Safety and Health (IOSH), Higher Education Academy (HEA) Engineering Subject Centre, European Network for Education and Training in Occupational Safety and Heath and the European Health and Safety Agency.

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Rui Fang Duan is a research student at the University of Liverpool under the supervision of Dr Graham Schleyer. She is assisting with the development of teaching materials, in particular, for the virtual laboratory which she co-ordinates and facilitates. She is also developing a prototype knowledge based system, as part of her PhD, for use by design engineers to help identify relevant literature for the identification of hazards, assessment and control of risk.

Richard Taylor is Visiting Professor at City University, London and Senior Research fellow at The University of Bristol. He chairs the Institution of Engineering and Technology's Health and Safety Policy Advisory Group and the Inter-Institutional Group on Health and Safety (IIG) and is a member of the Executive Committee of the Hazard's Forum. He is well known in the international nuclear community. He led work to develop the International Nuclear Event Scale (INES) and was a member of the International Nuclear Safety Advisory Group (INSAG) – the advisory group on nuclear safety to the DG of the IAEA from 1997 until 2003. He led INSAG work on safety culture, safety management and managing organizational change. He was until recently, Corporate Head of Environment, Health and Safety Policy for British Nuclear Fuels. Previously, he was Head of Environment, Health, Safety and Quality for Magnox Electric. After spending nearly 20 years in senior positions in the UK nuclear industry, Dick has now established his own consultancy, carrying out work for several major organizations in four areas of long-term personal interest and expertise – safety culture and leadership, change management issues, risk education and communication and more general safety risk management.

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