MARY KAY O'CONNOR PROCESS SAFETY CENTER
TEXAS A&M ENGINEERING EXPERIMENT STATION

21st Annual International Symposium
October 23-25, 2018 | College Station, Texas

Systems-focussed risk and process safety education

Ian Cameron, Paul Lant, Maureen Hassall
School of Chemical Engineering
The University of Queensland, Brisbane, Australia 4072
Email: itc@uq.edu.au

Keywords: Education, risk, process safety, systems thinking, professional practice, industry engagement

Abstract

Risk management and safety are at the core of performance in the process and manufacturing industries. Global studies by major consultancies show that mature risk management drives performance. That maturity considers a multifaceted risk perspective. Given the complexity of risk and process safety situations in industry a strong systems focus provides an effective means for establishing learning designs and driving student outcomes.

This paper describes the design principles, implementation, learning activities of two compulsory, integrated units in risk management and process safety within the School of Chemical Engineering at The University of Queensland. Two courses, one in the 4th year of the Bachelor's degree, and another in the 5th year of our Integrated Masters program were designed on the educational basis of the Knowing, Acting, Being (K-A-B) schema.

This curriculum model considers the key knowledge domains in each course, their interlinking, as well as active learning strategies to exercise the knowledge areas within a socio-technical systems approach. The 'Being' aspect focusses on the personal transformation in thinking, professional attitudes and dispositions of students. It aims at preparing students for professional practice.

Course design was done in conjunction with industry personnel, who continue to be involved throughout the course delivery, using live industry projects, and site visits to major hazard facilities. Learning activities are coupled to individual and group assessments that include significant industry case studies, consulting projects and professional standard reporting. Oral assessments or defence are used to get deeper insight into student learning.

The transformation and expansion of previous UQ risk and safety courses that are fully immersed in socio-technical systems has provided an extensive, solid educational framework that informs, challenges and equips student engineers for entry to professional practice.

Introduction and Educational drivers

We all know that process safety is paramount. Getting it wrong affects lives, damages the environment, sinks companies and stains many corporate reputations. You do not have to look any further than national or international news reports on major fires, explosions or toxic releases to realize the necessity of high quality education and practice to help address such disasters. In every case, a series of complex systems related failures combine to produce major disasters that affect people, societies, businesses, reputation, the environment and other important risk receptors.

For higher education, effective course design and delivery, to develop understandings of the fundamental principles and practices that lead to managing risks and ensuring process safety are both non-trivial and sadly rare.

Interest in this area of engineering higher education is however a key requirement of many global accreditation practices. Such professional accreditation bodies often have clear requirements and statements around risk and safety. For example, Engineers Australia (2018), emphasize the following Intended Learning Outcomes (ILOs) for engineering graduates:

ILO1. "Appreciates the principles of safety engineering, risk management and the health and safety responsibilities of the professional engineer, including legislative requirements applicable to the engineering discipline" [s1.6(b)]

ILO2. "Identifies, quantifies, mitigates and manages technical, health, environmental, safety and other contextual risks associated with engineering application in the designated engineering discipline"[s2.1(h)]

ILO3. "Executes and leads a whole systems design cycle approach including tasks such as: identifying assessing and managing technical, health and safety risks integral to the design process" [s2.3(c)]

ILO4. "Understands the need for 'due-diligence' in certification, compliance and risk management processes" [s3.1(b)]

Similar statements of required competences can be found in ABET[1], AIChE[2], IChemE[3] or EUR-ACE[4] documents and accreditation practices.

---

[1] ABET states under General Criterion 3: "(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability", http://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2018-2019/#GC2

[2] Outline of Guidelines for PEVs and Programs (31 Oct 2017). See: https://www.aiche.org/sites/default/files/docs/pages/pevprogram-guidelines-v2_10-31-17.pdf

One recurring theme that underpins such competences is that of a *systems* approach. It is the case that system conceptualizations with deep system thinking and quality decision making are needed as learners synthesize and analyze complex engineered systems. Those systems are not simply the interconnected plant items but are also concerned with human interactions often guided by procedural requirements in both normal and abnormal circumstances.

In this contribution, we focus on two key courses within the School of Chemical Engineering at The University of Queensland that specifically address risk and process safety education: one course at the undergraduate level and the other at masters level. The School has a long history back to the 1970s of providing formal courses that address process safety and risk.

The first course, CHEE4002: *Impact and Risk in the Process Industries*, is a compulsory course in the first semester of the final (4^{th}) year of the Bachelor degree in Chemical Engineering. It has a large cohort of approximately 200 students from all chemical engineering options that include chemical and also chemical/biological, metallurgical, environmental, materials degree options.

CHEE4002 course details are considered in an accompanying paper in this symposium authored by Lillburne, Lant and Hassall (2018).

The second course, CHEE7112: *Integrated Safety Design and Management*, is a compulsory course in the first semester of the final (5^{th}) year of the combined Bachelor/Masters degree. In contrast to CHEE4002, the cohort has approximately 30 students, again drawn from the various chemical engineering programs within the School.

In the next section we consider some curriculum design principles that can guide the development and effective delivery of learning, driven by a 'systems' perspective. The design principles also consider effective andragogy and assessment techniques that help provide evidence of learning.

Following the background concepts we show how we have taken these principles and created two courses that seek to develop knowledge, skills and professional attitudes in our graduates that prepare them well for entry into professional practice.

Curriculum and course design considerations

Systems thinking for risk and process safety

Any reading of major reports arising from official inquiries or commissions into significant disasters clearly spells out the system-based nature of the events and their connections. The BP *Deepwater Horizon* accident report (BP, 2010) stated factors behind the disaster to be:

---

[3] See Appendix A2.6 on Process Safety, and 3.3 on advanced masters qualifications: http://www.icheme.org/~/media/Documents/icheme/Membership/Accreditation/Accreditation%20guidance%20V20%20Final%2011%20Aug%202017.pdf

[4] See EUR-ACE under the European Network for Accreditation of Engineering Education (ENAEE), http://www.enaee.eu/accredited-engineering-courses-html/engineering-schools/accredited-engineering-programs/

> “*A complex and interlinked series of mechanical failures, human judgments, engineering design, operational implementation and team interfaces came together to allow the initiation and escalation of the accident.*“

Figure 1 gives an overview of the two key elements within a systems perspective. That perspective sees the real world as made up of *elements* or *parts* with *capabilities.* Along with their *interconnections* this provides the *functions* to ultimately fulfil *intended goals.* We briefly discuss those system concepts and will later show how they are considered within risk and safety education.

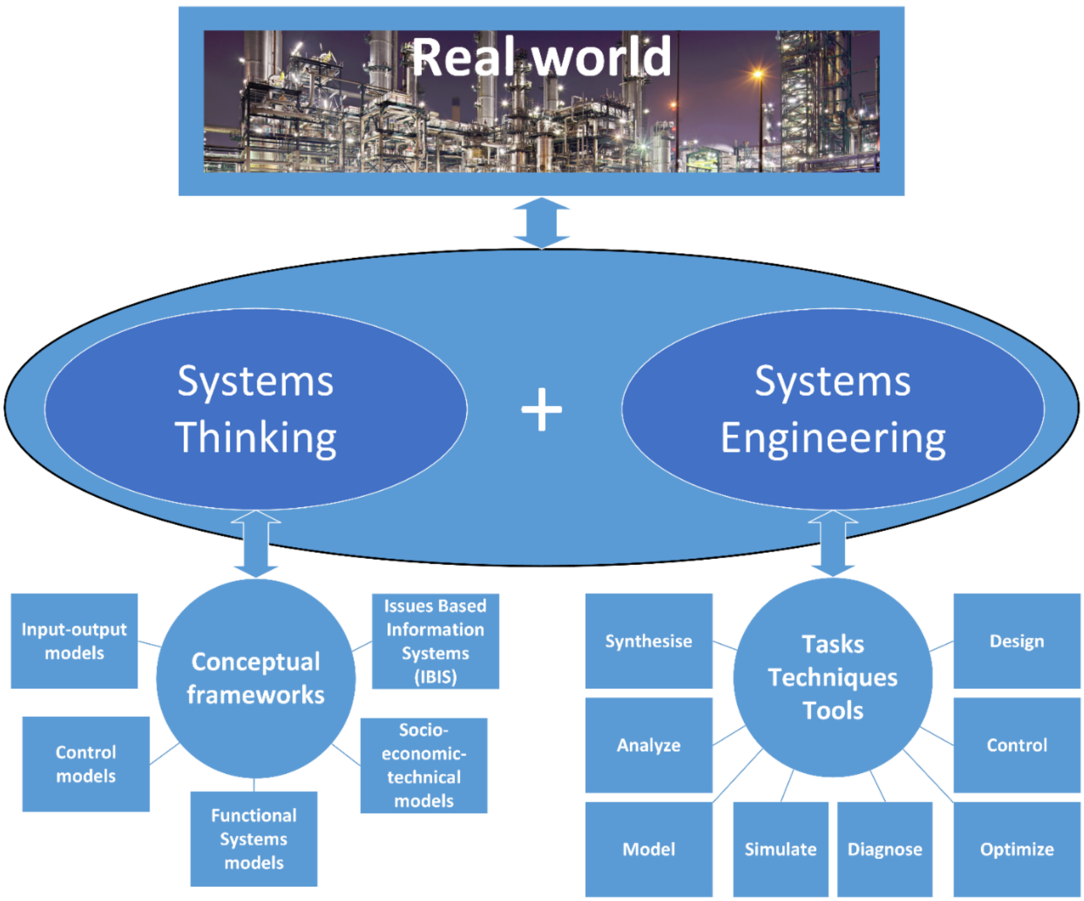


Figure 1 Representative components of a systems perspective

- *Key Aspect 1: Systems thinking*: exercises the skills and mental activity that forms and arranges in our mind ideas about the system. This allows us to address a wide range of outcomes. In doing so, we can employ a number of helpful conceptualizations that aid and organize our thinking. It helps address the issues around complexity.

  These conceptualizations can include:

  - *Input-output models*: considering system inputs and outputs, typical of process systems representations.

  - *Control models*: considering inputs (manipulated variables), disturbances (unmeasured and measured) and outputs (controlled variables), often incorporating feedback and/or feedforward aspects or embedded control models.
  - *Functional systems models*: these explicitly incorporate design intent into the models, as well as operational modes, system tasks, methods and constraints. They introduce concepts of capability, function and failure.
  - *Socio-technical-economic models*: these consider the wider setting of engineered systems by introducing consideration of engineered designs, human factors as well as procedural aspects, all this set within a company culture and a much wider social and environmental setting.

  A final social sciences conceptualization framework known as *Issues-Based Information Systems* or IBIS becomes important in risk and safety education. It provides a formal structure that captures the interrelations amongst issues, positions and arguments that are behind the various decisions made as learning activities such as projects are performed. This helps shape students' critical thinking and decision making.

- *Key Aspect 2: Systems engineering*: which consists of Tasks, Techniques and Tools applied in addressing risk and safety issues. Those tasks range from system synthesis and analysis, through modelling, diagnosis, optimization and design. To carry out tasks, a range of techniques can be deployed that often make use of numerous digital tools.

Systems concepts and practices are vital ingredients in learning design, as we now discuss.

Educational design principles

In considering the educational importance of risk and safety, key graduate outcomes can be formulated across three main areas:

- the knowledge areas that are to be acquired,
- the capabilities to take up knowledge and use it in familiar, new and challenging situations, and
- the professional attitudes, dispositions and personal skills required and developed

These three areas of *Knowing*, *Acting* and *Being*, form a schema (Barnett & Coate, 2005) as seen in Figure 2. This schema or variants of it[5] can be used for the design of learning units and curricula.

[5] Other concepts such as the *Episteme, Techne, Phronesis/Praxis* (Knowledge, Technique/tools, Practical wisdom/conduct) nexus can help drive course designs for intended learning outcomes. These issues are Aristotelian in origin.

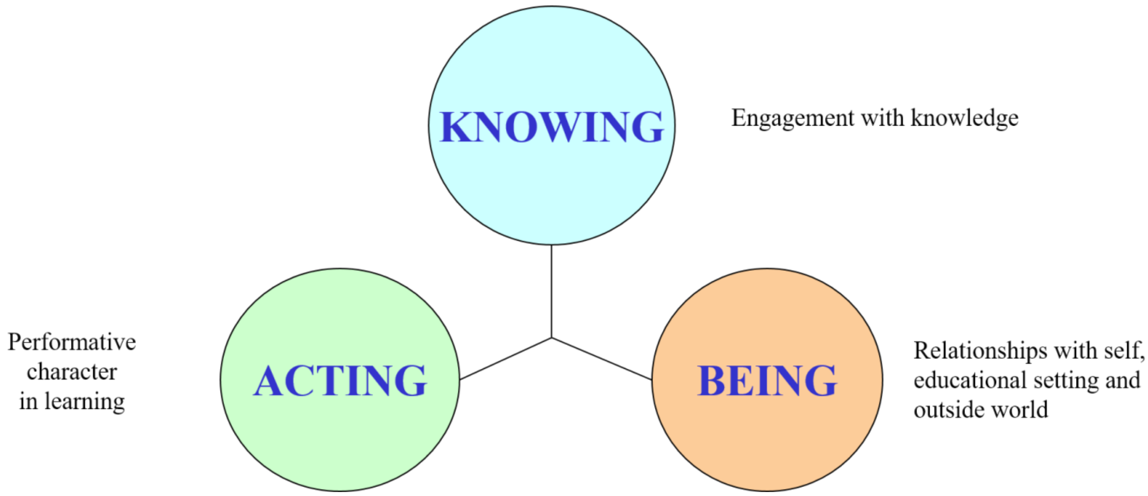


Figure 2 The Knowing-Acting-Being (K-A-B) schema for learning and design of curricula

In considering the K-A-B schema, we can identify that the 4 previously mentioned professional engineering accreditation requirements from Engineers Australia primarily relate to *Knowing* (*ILO1*), *Acting* (*ILO2, ILO3*) and *Being* (*ILO4*). Other accreditation jurisdictions are similar.

This schema can then help drive course design and also help in considering the interaction across years and courses. Those 3 focus areas of curriculum learning outcomes must be accompanied by a range of learning activities and student responsibilities. In the following section we discuss a set of interconnected course aspects that can guide learning activity choices.

Andragogy and learning activities

Andragogy describes a learning environment that incorporates a significant move towards self-directed learning. This learning model is essential for those moving into early-stage professional practice. It contrasts with the concept of pedagogy which is primarily teacher driven learning.

To help focus attention on learning designs that incorporate effective components to promote learning, Figure 3 captures some key considerations in addressing the theory-practice nexus.

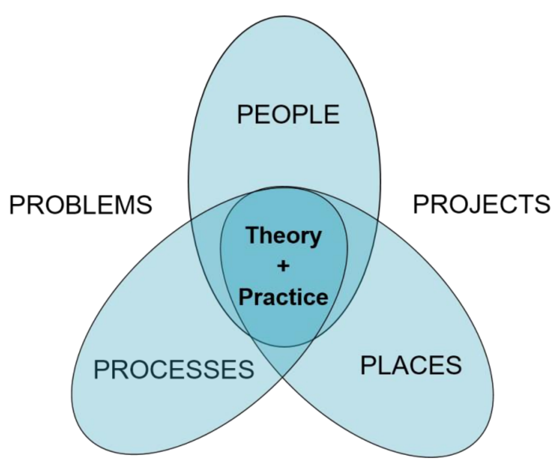


Figure 3 Dimensions of creative learning environments (5Ps model)

The concern in course and curriculum design and delivery is not just knowledge acquisition but also the development of competences in applying knowledge, skills and methodologies to complex risk and safety situations. We are very interested in the development of personal, professional attitudes and dispositions regarding risk and safety.

The dimensions of importance for educational design are:

1. *People*: what people will students meet and engage with during learning activities?
2. *Places*: what places and spaces will the students use and/or visit that will enhance their learning and drive the development of professional skills and attitudes?
3. *Processes:* what learning approaches and activities are best suited to drive ILOs? What should be the individual and team responsibilities within the course? And importantly, what range of assessment techniques should be adopted to provide proof of learning?
4. *Problems:* what types and complexity of problems should student confront in developing application abilities
5. *Projects:* what type and complexity of projects should be adopted to exercise a range of systems models that help address complex designs and operational scenarios?

Innovative course design comes from clever, engaging and interesting ways that students traverse the learning journey guided by these 5P dimensions. The following section illustrates some applications of these engagement dimensions.

Design and deployment of systems-focussed education in UQ risk and safety courses

In this section we discuss two current courses within the School of Chemical Engineering that provide education to 4th and 5th year students. The goals of these courses are presented, the various systems perspectives are laid out, and the use and importance of the chosen learning activities are described. The two courses are:

- CHEE4002 Impact and Risk in the Process Industries
- CHEE7112 Integrated Safety Design and Management

We now discuss the details of these courses, and emphasize important educational design features from both.

CHEE4002 Impact and Risk in the Process Industries

The intention of this course is to develop 5 learning themes:

1. Understanding risks and their impacts – from technical, human, social, and environmental perspectives.
2. Professional engineering practice and risk – values, ethics, behaviour, accountabilities and obligations
3. Modern risk management approaches and tools
4. Humans and risk
5. Sustainability and risk

The course is based on a broad view of industrial risk management concepts shown in Figure 4.

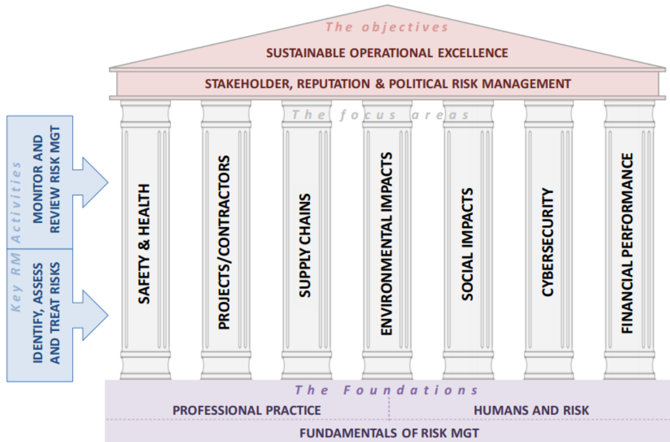


Figure 4 Scope of risk management considerations in CHEE4002

Figure 5 gives a structured map of key elements within the course. This shows the major system models that drive learning and importantly the student activities and assessments (Hassall & Lant, 2017).

Similar to CHEE7112 this course makes significant use of case studies, because:

1. They help build knowledge around the complexity of socio-technical systems,
2. They encourage systems thinking to unravel the role of "agents" and interconnectivity,
3. They utilize "story telling" which engages learners in their educational journey, and,
4. They emphasize the need for them to develop professional skills and attitudes

An important point is the assessment strategy. The strategies and assessment types help drive an "active learning" approach, with team-based case studies and projects accompanied by individual accountability in several assessment tasks and oral examination.

The course is "fit-for-purpose" for our Bachelor graduates and is very well regarded by the professional accrediting bodies – both Engineers Australia and IChemE as excellent preparation for entry into professional practice.

The reader is encouraged to look at the accompanying paper by Lillburne, Lant and Hassall in this symposium proceedings which details more in-depth information.

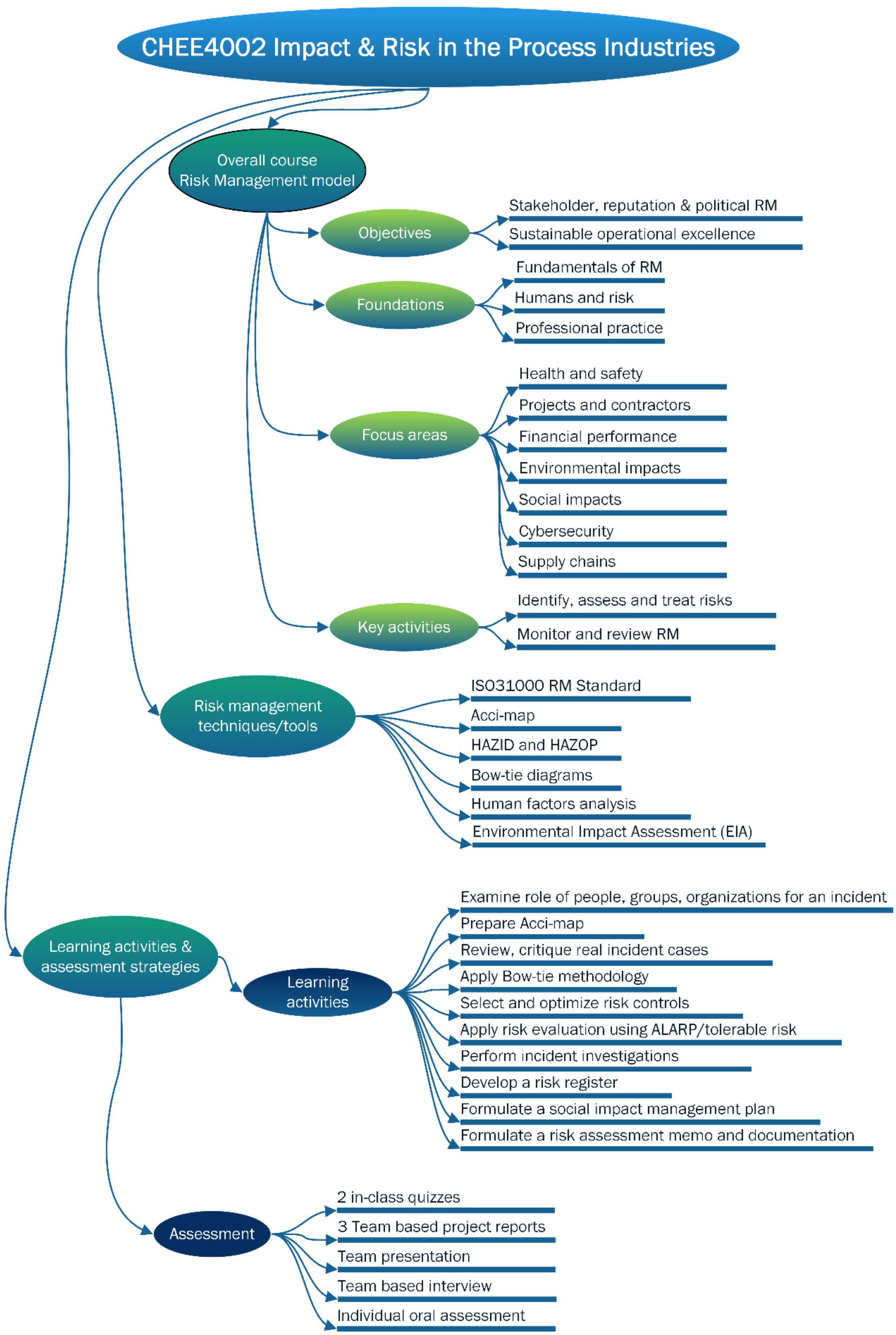


Figure 5 Structural components of CHEE4002 Impact & Risk in the Process Industries

CHEE7112 Integrated Safety Design and Management

The intention of CHEE7112 is to build upon prior learning in CHEE4002. The aims include:

1. Discern and evaluate existing and emerging system models that underpin approaches to dealing with risk and safe operation in complex industrial designs.
2. Develop and investigate Acci-Map representations to enhance insights around complex system failures and interactions.
3. Analyse complex industrial systems to determine best actions in design to address risks through inherently safer design principles
4. Critique and perform LOPA studies so as to assess risk levels and risk reduction strategies related to process plant
5. Analyse and specify the need for safety instrumented systems (SIS) for specific industrial case studies.
6. Evaluate the interaction of humans within complex engineered systems in order to enhance system resilience.
7. Investigate, analyse and design strategies for operator actions in industrial applications using cognitive work analysis (CWA) and strategy development and assessment

The overall structure of CHEE7112 is shown in Figure 6. The approach has the following characteristics:

1. A very strong systems fundamentals emphasis around formal system theory and deployment that deals with function and failure
2. In-depth considerations of qualitative and quantitative risk and safety issues
3. Application of a range of system models to complex process circumstances and critical examination of their applicability
4. Working on real industry projects or major system failures as consulting teams with time, financial and confidentiality accountability to the industry client.
5. Engagement with a wide range of professionals from senior process engineers, safety and operational risk experts, senior industry risk managers to heads of government regulatory agencies.

Having established the intended learning outcomes of this course the embedding of systems concepts, systems thinking and its use will be discussed as well as use of the 5Ps learning model.

The embedding of systems concepts, thinking and use into courses

The use of systems to help guide thinking and learning activities is paramount in the design of the two courses. Figures 5 and 6 show the range of system-based ideas used within each course as well as the assessment strategies and types. We now look at the importance of those learning design ideas, as summarized in Figure 3.

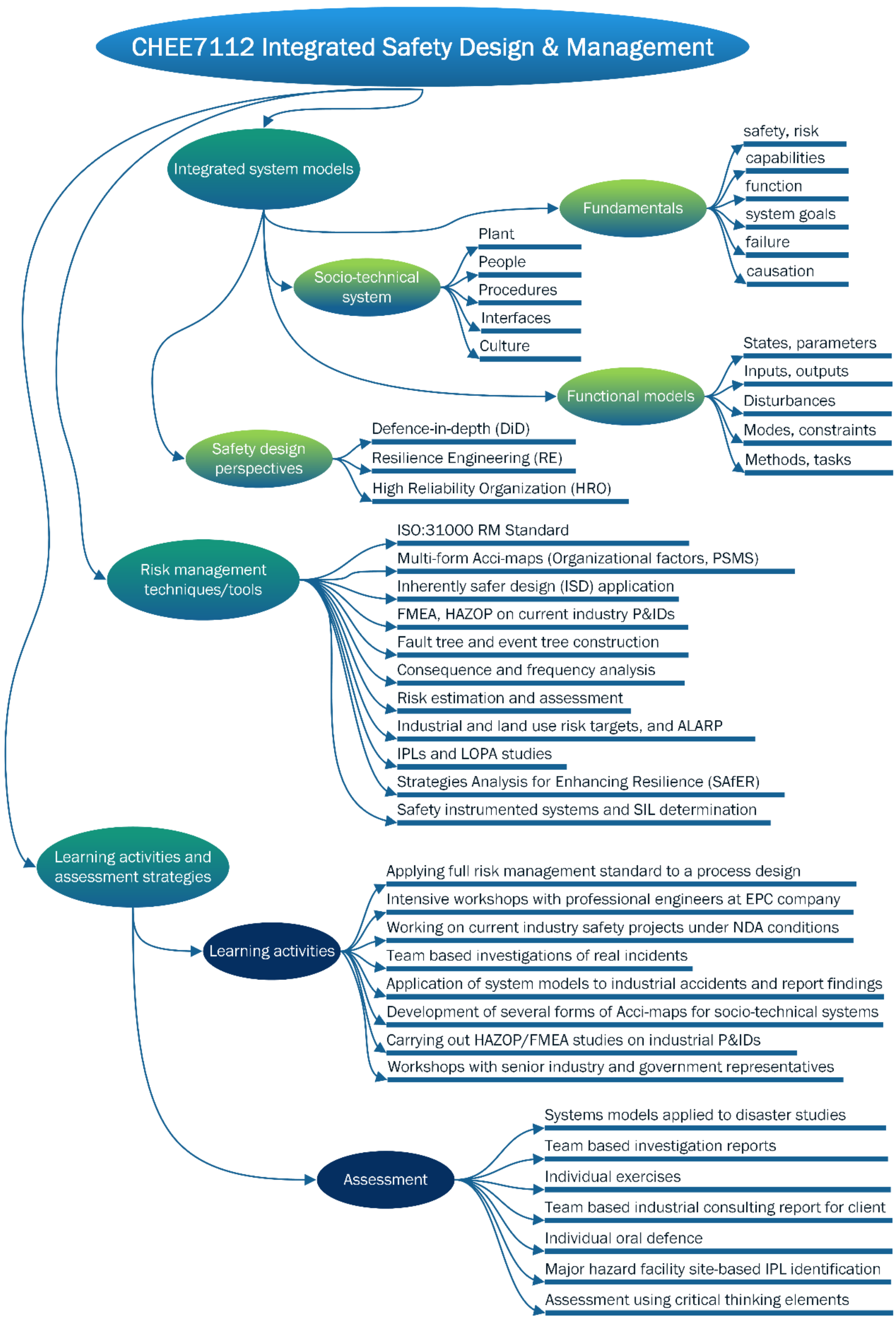


Figure 6 Structural components of CHEE7112 Integrated Safety Design and Management

Systems perspective and thinking

Ideas here include:

- Introducing students to system models that have the ability to capture the key components of the real world. They help direct and organize deep thinking and understanding of complex engineered systems
- A range of system conceptualizations that move from the simplest input-output models to socio-technical models that capture a much wider range of ‘actors’, viz. plant, people, procedures, management, culture and societal/environmental settings.
- Application of these models to a significant number of case-studies and industry projects, where insights, decision making and critical thinking can be developed

People

This involves interactions with:

- Academics
  - Engaging with existing and recent knowledge developments in the field
  - Seeing a diversity of views and expert discipline areas (Engineering, Psychology, …)
- Tutors
  - Personalized engagement in knowledge and application
- Senior industry and government personnel
  - The vital role of process safety and risk leadership
  - Exposure to professional attitudes and dispositions
  - Deep knowledge and practice is shared
  - Organizational cultures articulated and how they shape thinking and behaviours
  - Theory and practice seen together in work situations
  - Grasping the challenge of government responsibilities in a wider social context
  - Role and importance of high quality auditing
- Industry and EPC senior engineers/staff and operators
  - The role of engineers in assuring safety-in-design as a regulatory requirement
  - Importance of multi-disciplinary teams and thinking around complex designs
  - The role of time and cost to deliver high quality solutions to clients/company
  - Exposure to professional practice, techniques and tools
  - The importance of life cycle information systems and decision making documentation

Places

This involves taking student engineers into places with key affordances:

- Corporate offices: which provide opportunities to engage students with practising engineers, managers and consultants
- Collaboration areas: that facilitate student teamwork, proto-typing ideas and displaying thinking

- Virtual spaces: such as 3D walkthrough, observation and interrogation of plant such as our BP Refinery VR environment
- Industry places: where student teams can see the process plant under study, appreciate equipment scale, engage with engineers, senior managers, see a range of control stations and speak with operators around the situations and decisions to be made when abnormal conditions occur

Processes

This involves a wide range of learning activity and assessment models:

- Learning activities, can include:
    - Pre-recorded presentations on theory or fundamental concepts
    - Workshops where theory and practice meet in a specific risk or safety situation
    - Video presentations/sessions on many risk/safety topics, sourced globally
    - Case studies, drawn from a wide range of industries (Oil-gas, minerals, food, bio, …)
    - Industry sponsored projects
    - Debates around contentious topics such as land use planning for major hazard facilities
    - Visiting speakers that challenge student thinking and deal with issues such as ethical dilemmas.
- Assessment should be aligned to the intended learning outcomes, and these courses use a range of approaches that include:
    - Individual, focussed exercises for understanding and skill development
    - Team-based case studies and industry projects with substantial feedback
    - Team-based presentations to class and industry clients
    - Team oral assessments
    - Individual oral defence around theory and practice issues
- Formal critical thinking elements and project assessment rubrics

Finally we set out some ideas around the Problems and Projects aspect of our learning environments.

Problems

These can be classed as questions raised for discussion and/or solution. Most are focussed on individual knowledge, application and skill development. In these risk and safety courses they might typically be:

- An exercise to classify process system variables into: states, inputs, disturbances and outputs. This understanding can then be used for more complex team activities.
- An estimate of the physical effects from a specific loss of containment situation giving rise to a fire (thermal radiation), explosion (overpressure/duration) or toxic release (concentration).
- The application of ISD principles to a set of reaction pathways for a specific chemical compound.

    These types of problems are to drive student learning and help assess their individual capabilities

Projects

These activities are focussed on providing collaborative, team-based learning that requires significant research, deep investigation and insights around process design and human factors considerations, operational and management issues. They require careful planning, execution and professional reporting that is constrained by time and cost. In CHEE7112 the active learning strategy is driven primarily through projects: some on available case studies but other specifically sourced from major operating companies. Typical projects around risk and process safety have been:

- Addressing design, control and operational improvements for a naphtha separation unit.
- Examination of ship-to-shore fuel transfers for a major flammables fuel terminal.
- Study of facility design and operations, including key human factors for LPG export
- Design and operational investigation for new bulk liquids terminal for land use planning requirements
- Study of the design and operations of a catalytic polymerization unit
- Incident review of an isomerization unit for design, control and operator performance improvement.

These are projects that bring together complex chemical and physical processes, large DCS data sets, process engineering information and documentation including PFDs, P&IDs, SoPs, emergency response plans, along with actual control performance and operator screen designs. It provides a realistic immersion into real-world risk and process safety situations.

Summary and conclusions

Systems perspectives in risk and safety studies are absolutely essential. Higher education will fail our graduate engineers if they cannot grasp the complexities and the required integrity of engineered systems with considerations of process safety management and the vital role of human-centred design considerations. We believe that exposure to, and use of, various ‘systems’ perspective will better prepare our graduates for entry into professional practice.

We have set out some of the important systems-based concepts that form the foundation of two compulsory risk and safety courses in Chemical Engineering at The University of Queensland. Response from students has been extremely encouraging, that these courses help inform their knowledge around risk and safety issues, as well as developing basic skills in risk management practice.
Other evidence suggests that students recognize the importance of growing their professional attitudes, dispositions and skills around risk and safety via these learning pathways

Our experience with industry collaboration, EPC companies and government agencies has been excellent in terms of ready access to facilities, staff and challenging projects that add significant reality to the learning journey. As well, we have established excellent working relationships with other academic discipline areas such as psychology, philosophy and business that adds significant value to the student experience.

We continue to review, explore and focus on providing excellent learning design and pathways for our graduates. For us, the journey is never really finished!

References

ABET (2018), *Criteria for Accrediting Engineering Programs*, *2018-2019*, see: http://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2018-2019/#GC2 Accessed July 27.

AIChE (2017), *Outline of Guidelines for PEVs and Programs, PEV and Program Guidance Subcommittee,* See: https://www.aiche.org/sites/default/files/docs/pages/pevprogram-guidelines-v2_10-31-17.pdf Accessed July 27.

Barnett, R and K. Coate (2005), *Engaging the Curriculum in Higher Education*, Open University Press.

BP (2010), *Deepwater Horizon* Accident Investigation Report, September 8. (see page 31). https://www.bp.com/content/dam/bp/pdf/sustainability/issue-reports/Deepwater_Horizon_Accident_Investigation_Report.pdf Accessed July 31.

ENAEE (2018), Standards and Guidelines for Accreditation of Engineering Programmes, See: http://www.enaee.eu/accredited-engineering-courses-html/engineering-schools/accredited-engineering-programs/ Accessed July 27.

Engineers Australia (2018), *Stage 1 Competency Standard for Professional Engineer,* see: https://www.engineersaustralia.org.au/sites/default/files/resource-files/2017-03/Stage%201%20Competency%20Standards.pdf, Accessed August 31.

Hassall, M. E. and P. Lant (2017). *Teaching Risk: a New Approach*, The Chemical Engineer, The Institute of Chemical Engineers.

IChemE (2017), *Accreditation of chemical engineering programmes: A guide for higher education providers and assessors.* See: http://www.icheme.org/~/media/Documents/icheme/Membership/Accreditation/Accreditation%20guidance%20V20%20Final%2011%20Aug%202017.pdf Accessed July 27.

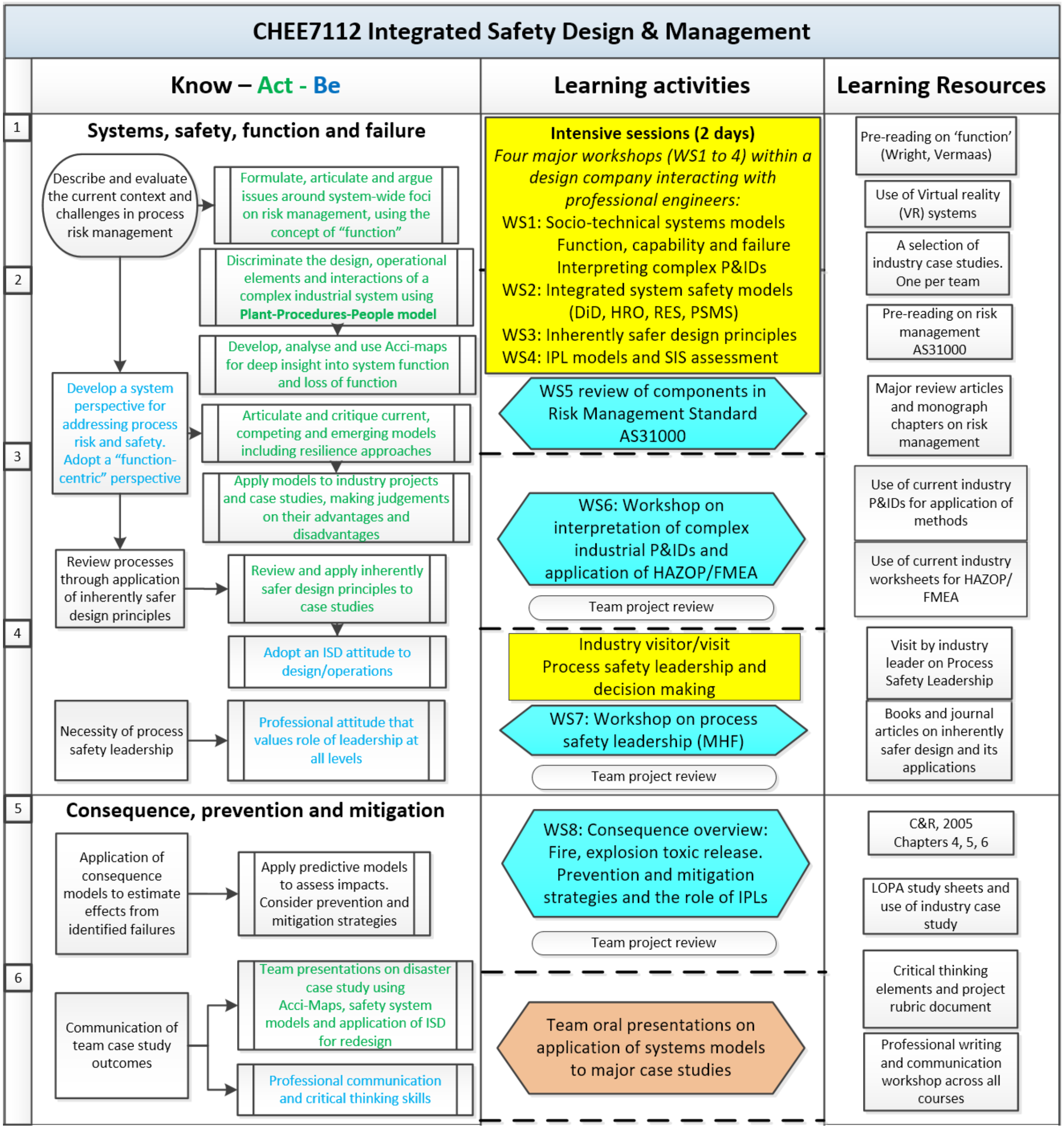
Lillburne, C., P. Lant and M. Hassall (2018), *Flipping the assessment model: Teaching and assessing 'things that matter'*, MKOPSC International Symposium, Texas A&M University, College Station, Texas, USA.

Werner, Kunz and Rittel, Horst (1970), *Issues as Elements of Information Systems*, Working paper No. 131, Studiengruppe für Systemforschung, Heidelberg, Germany, July 1970 or see full entry at: https://en.wikipedia.org/wiki/Issue-based_information_system Accessed July 27.

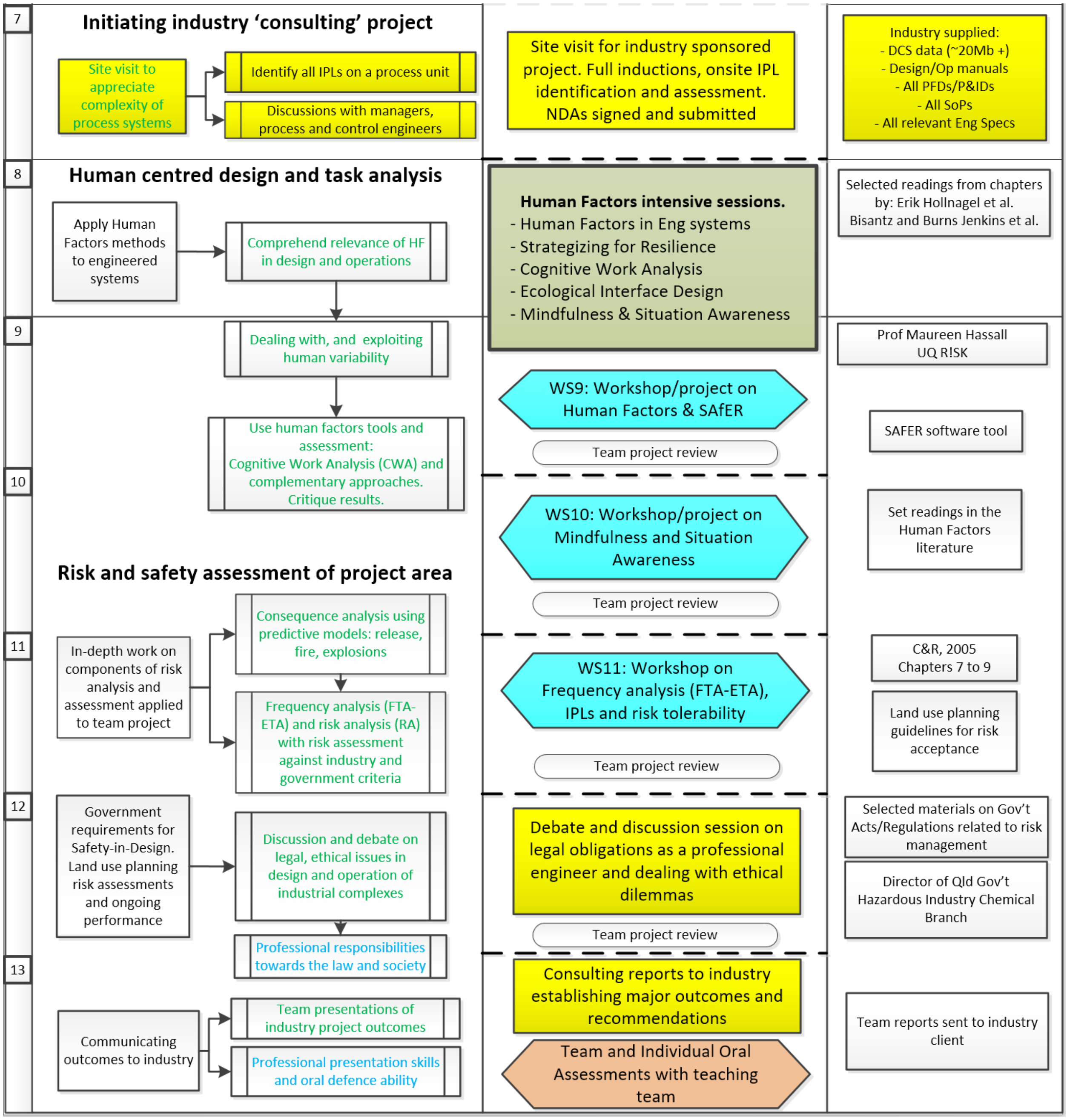
APPENDIX: The learning pathways for CHEE7112

This shows the intended learning pathways design or pathway over a 13 week seminar, summarising the K-A-B elements, learning activities and some of the many resources available to students.

First half of semester:



Second half of semester:



Other information on these courses is openly available on The University of Queensland website at:

For CHEE4002: https://my.uq.edu.au/programs-courses/course.html?course_code=CHEE4002

For CHEE7112: https://my.uq.edu.au/programs-courses/course.html?course_code=CHEE7112