Civil and Infrastructure Engineering for Sustainability

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Introduction

In 2002, the School of Civil and Chemical Engineering at RMIT University began a project to renew its Civil Engineering program, ready for the new 2004 academic year. This program had high acceptance in the marketplace (high graduate employability) but average student satisfaction scores (as measured by the national CEQ data).

As part of this renewal process, it was decided to shift the focus from traditional civil engineering to "infrastructure engineering", the intention being to prepare students for the whole life cycle of an infrastructure facility, rather than just the detailed design phase.

The renewal process itself was sponsored by the university as part of its Teaching and Learning Strategy [1] – basing all new programs on *graduate capabilities*. This matches the approach taken by ABET [2], ASCE [3], as well as Engineers Australia (formally IEAust) [4]. Details of the approach were reported at the ASEE 2003 annual conference [5].

The Capability Approach

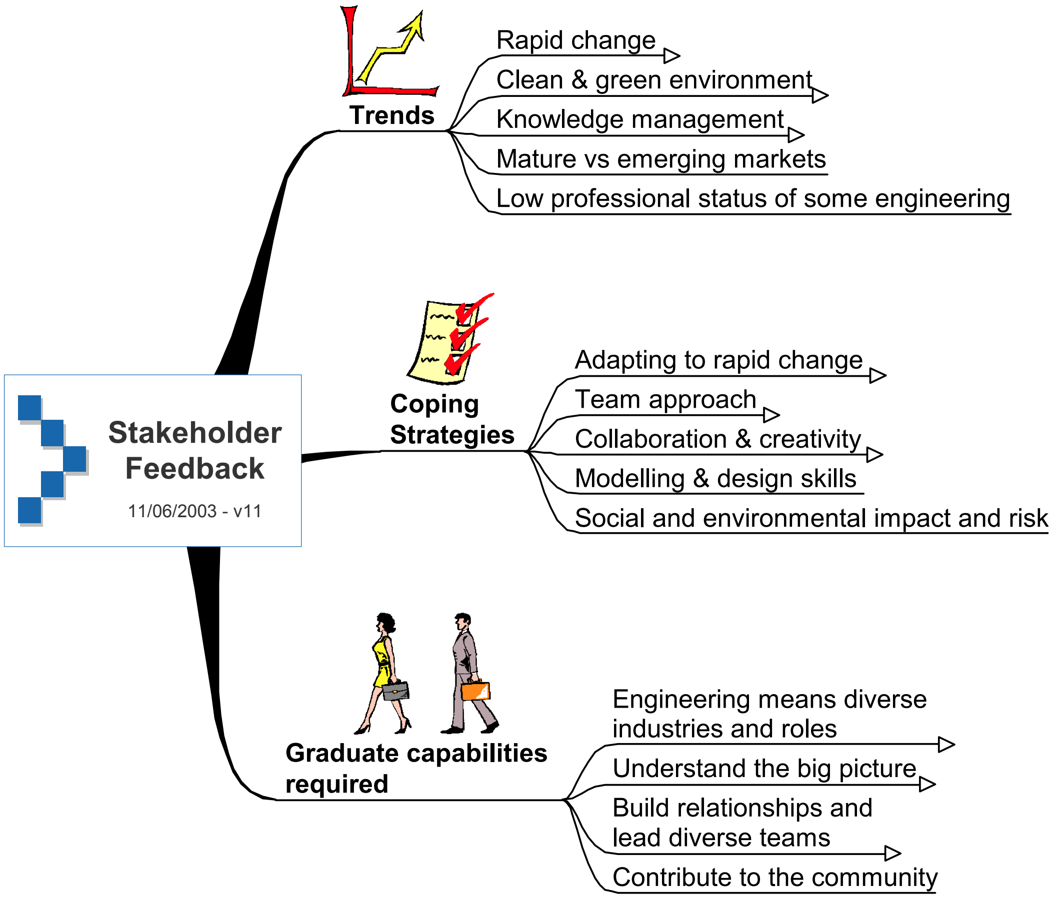
Curriculum renewal has been based on capability theory [6] and socio-ecological systems theory [7] as described by Hadgraft & Muir [8].

A series of industry meetings was held with a range of engineering employers and graduates to seek their input into the new program. The key questions asked at this forum were:

1. What are the *emerging trends* in the environment that are impacting your organization?
2. What *attributes* will your organization require if it is to survive and thrive in this environment?
3. How are you, and your organisation, *dealing/coping* with the pressures to survive and thrive?
4. What *capabilities* will employees, specifically, graduate engineers, require if they are to effectively contribute to their work organisations and communities into the 21st Century?
5. What can or should be done to ensure that these young engineers are *better prepared* to meet the demands in their lives as professionals and citizens?

The details of the stakeholder feedback are provided in the Appendix.

In parallel with the civil engineering meetings, similar meetings were held with stakeholders for the Chemical Engineering, Environmental Engineering and Geological Engineering programs. Some details of the chemical engineering discussions have been reported elsewhere [8]. A number of common trends emerged from these meetings, providing a consistent set of messages for the capabilities required in new graduates [5]:



Capabilities

From this consultation process, the following capabilities were identified:

- *Sustainability* – Balance the technical, economic, environmental and social demands of a problem; Protect safety, health, and welfare.
- *Problem solving and decision-making* – Model engineering problems using a systems approach and appropriate assumptions; Use a range of decision making (evaluation) methodologies; Identify the criteria to be used in decision making (eg sustainability); Use a range of engineering analysis tools and software; Access information from a wide variety of sources, discern value and use; Design and conduct experiments
- *Technical competence* (engineering analysis) – Conceptualise, plan, design, construct and manage civil infrastructure systems; Analyse and interpret field and laboratory data
- *Teamwork and Leadership* – Operate within an engineering organisation; Manage projects and contracts; Develop quality plans; Provide constructive feedback to team members; Resolve conflict in a team; Lead a team; Work with other disciplines in a team with conflicting needs
- *Communication* – Communicate effectively – listen, observe, speak, draw and write ; Communicate results qualitatively, quantitatively, graphically, electronically, textually;

Communicate processes of thinking and reflection (including giving constructive feedback)

- *Personal Development* – Be conscious of their own values; Adhere to professional ethics; Plan their career; Reflect on experience; Improve their own future practice; Engage in Lifelong learning

Sustainability

A key graduate capability that emerged was the need for an understanding of and operational skills in the use of sustainability principles in each engineering discipline. This was strongly supported by industry participants. It represents a significant departure from traditional engineering programs that tend to focus on detailed knowledge of engineering science principles. Such a shift is supported by Johnston [9] and others.

Nevertheless, sustainability has been a key issue within the School of Civil and Chemical Engineering for some time. The environmental engineering program at RMIT is one of the first in Australia, dating from 1991. The chemical engineers have also run a Master of Cleaner Production since 1995. The new program will also draw from a range of resources within and beyond RMIT.

The University itself established a centre for Global Sustainability @ RMIT several years ago [10]. The aims of this centre are set out on its website:

> *Globalisation, revolutions in information and communications, environmental and community awareness and action are driving corporate and political leaders and citizens to address the future in very different ways.*
>
> *Companies, government and non-government organizations are looking to new concepts and methods to operate. The Triple Bottom Line Plus One (environmental, social & cultural, economic, governance) provides a systematic approach to begin to unravel just how we might work in the 21st century.*

This quote neatly summarises some of the key issues that emerged at the stakeholders' meetings, namely globalisation, information and knowledge management and community awareness, leading to the need for a triple bottom line approach.

During the latter half of 2002, a project was initiated to expand these ideas within the context of engineering [11]. This report defined the sustainability capabilities as:

1. *Understanding of, and commitment to, the principles of sustainability and sustainable development, including the ethical foundations of these concepts, and the ability to exercise considered judgments based on these principles in real-life situations.*

2. *Ability to assess and evaluate the importance of social, environmental and economic (as opposed to simply internal financial) impacts of a project, technological development, new process or product, using a holistic systems approach, with a scope encompassing all communities and natural resources affected.*

3. *The skills to communicate, listen, negotiate, resolve conflicts and work harmoniously with impacted communities.*

4. *Ability to engage in 'sustainable design' – of production processes, products, plants and other facilities, technologies, and projects – so that social, environmental and economic sustainability criteria guide the design process right from outset, and the maximal sustainability outcomes are obtained.*

An additional project, still continuing, is the development of a set of learning resources to support teaching in sustainability. These resources will soon be available from the Global Sustainability @ RMIT website [10].

The Institution of Engineers, Australia has provided an overview of sustainable engineering [12]. This document describes how: Engineers can play an important role in sustainable development by planning and building projects that preserve natural resources, are cost-efficient and support human and natural environments. It provides examples of good engineering practice in each of these areas. These examples can be adapted as learning activities (projects) within an engineering program.

The Australasian Virtual Engineering Library [13] describes itself as a Sustainable Knowledge Network. It includes the Green Design and Sustainability Portal [14] and the UNESCO Virtual Engineering Library for Sustainable Development (under development).

Other knowledge portals include iConnect [15], e4engineering [16] and inKNOWvate [17].

The ASEE provides the Engineers Forum on Sustainability [18], which hosts a regular newsletter on sustainability issues.

All of these links are available to students through the Skills for Sustainable Engineering website [19].

Teaching Methods

The challenge for all new engineering programs is to develop the capabilities in the students. Traditional curricula are well suited to cognitive capabilities, eg engineering science, but relatively weak where affective, behavioural and social capabilities are required. New teaching methods are required.

The redesign of the civil and infrastructure program has introduced a spine of Engineering Practice courses that embody the key professional capabilities. Each semester contains one of these courses:

Semester	Title	Purpose
1	Skills for Engineering	Semester 1 is the key bridge between school and university. *Skills for Engineering* will encourage student motivation by helping them to **connect themselves to engineering** (the theme for year 1) [eg, see 20]. They will be introduced to the breadth of graduate capabilities described above through a small project that will link to the other courses in the semester (Statics, Maths, Chemistry and Physics).

Semester	Title	Purpose
2	Environmental Principles for Sustainable Design	Semester 2 continues the task of bridging from a science based school program to our engineering program. *Environmental Principles* focuses on sustainable design and environmental principles, introducing the concept of the triple bottom line through a small design project.
3	Mathematical Modelling	Year 2 is the year that focuses on the **big theoretical ideas**. Engineering Practice focuses on mathematical modelling. This semester was deliberately chosen to align with Water Engineering and Transport Engineering so that examples from those disciplines could be used in mathematical modelling tasks.
4	Engineering Economics and Project Evaluation	In semester 2 of year 2, Engineering Practice covers construction economics and project evaluation according to the triple bottom line. This is stage 2 of the development of skills in sustainability.
5	Construction Management	Year 3 is the **Year of Engineering Applications**. At this point, students begin to choose courses that match their own intended career directions. In semester one, Engineering Practice is focussed on Construction Management, which develops capabilities in project management, contracts, quality and risk management. Sustainability issues, eg environmental effects during construction, are a component of this course.
6	Sustainable Infrastructure Design	In semester 2 of year 3, students tackle a small eco-design project. In 2003, a trial run of this course was implemented using the *Your Home* site as information source [21]. Students developed a design for an eco-efficient home. Other sources of information are the Green Building Council of Australia [22] and the US GBC [23] as well as [24,25].
7	Investigation Project (individual)	Year 4 **connects students to the workplace**. The Engineering Practice course in semester 1 is an individual investigation project. This allows students to demonstrate the range of capabilities developed through the program in an autonomous context. These reports are often key assets at job interviews because they demonstrate what each student is able to achieve when working autonomously. This course will also be used to further counsel students about their future career directions.
8	Infrastructure Project (group-based)	In semester 2 of year 4, students work on a project that covers one or more aspects of the lifecycle of an infrastructure asset – planning, design, construction, operations and maintenance. Students will be required to demonstrate how their solution matches sustainability principles.

These Practice courses embed the *year themes* through *project-based learning* as described previously [5].

In somewhat more detail, the second of the Engineering Practice courses, Environmental Principles for Sustainable Design covers:

> *… an introduction to the environmental principles and practices in the engineering and mining professions. The topics covered include: environmental impact assessment, the concepts of sustainability and sustainable development, the Institution of Engineers Australia (IEAust) environmental principles for engineers and the code of ethics, community consultation, energy and greenhouse, cleaner production, environmental management systems and case studies of environmental practice in engineering and mining projects. A field class is held to gain an appreciation of the environmental issues involved in the planning, design, construction and maintenance of engineering projects.*

Objectives / Learning Outcomes

On successful completion of this course, you will be able to:

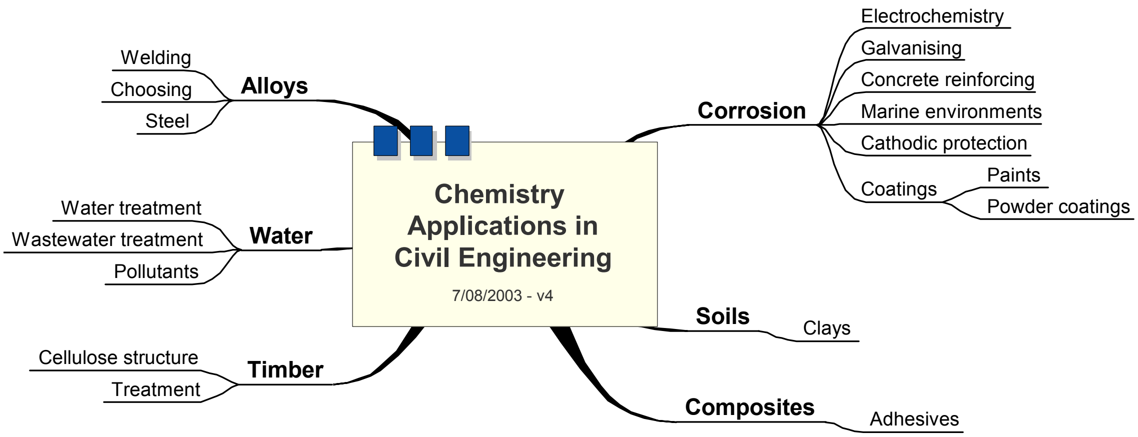
- *Explain how the need for environmental policy developed.*
- *Prepare a rudimentary EES for a project.*
- *Recognize environmental issues pertinent to projects.*
- *Explain the principles governing environmental best practice.*
- *Debate environmental issues within the context of sustainable professional practice.*

Detail of other courses is available on request.

Team teaching

The implementation of such an integrated program has required a greater commitment to team-based teaching. Most notably, this is happening through the use of *semester management groups* to provide the cross-linkages and coherence between the teachers of the individual courses, including service teaching from other parts of the University.

The first semester management group (SMG) has been meeting since mid-2003. It is made up of the teachers from Engineering Practice, Statics, Mathematics, Chemistry and Physics. The design of the latter three courses was based around engineering examples. The following mindmap shows applications developed for chemistry. These applications provide motivation for students to learn chemistry, which is no longer an entry pre-requisite for civil engineering at RMIT. Details of applications in mathematics and physics are available on request.



Initially, it was not clear to SMG members what the role of the SMG would be. One opinion was: *Now that we've designed the courses, can't we just get on and teach them?* Early discussions encouraged looking for common threads that would bind together teaching from different courses. For example, physics and mathematics could be linked through differential equations. Vectors popped up in statics, mathematics and physics and so on. As the discussions evolved, more and more cross-linkages were identified. The whole semester's work was mapped out week by week. Common themes were aligned by shuffling topics between weeks. The focus in this semester is helping students make the *connection to engineering*. This requires helping them see the connections between the mathematics, physics and chemistry that they bring from school and the applications in engineering, most notably statics in first semester.

The second semester management group has also begun to meet to develop a similar program of integrated work. In this semester, students begin to see the wider application of engineering in the world, with its effect on the environment, economy and society (people, planet and profits). They (the students) will work on another small design project, in groups, implementing these principles in a real engineering context. This design will be linked to their structural analysis course, in which they learn basic structural mechanics.

In 2004, semester management groups for years 2 and 3 will meet to map out those years, both of which will be implemented in 2005.

Summary and Conclusion

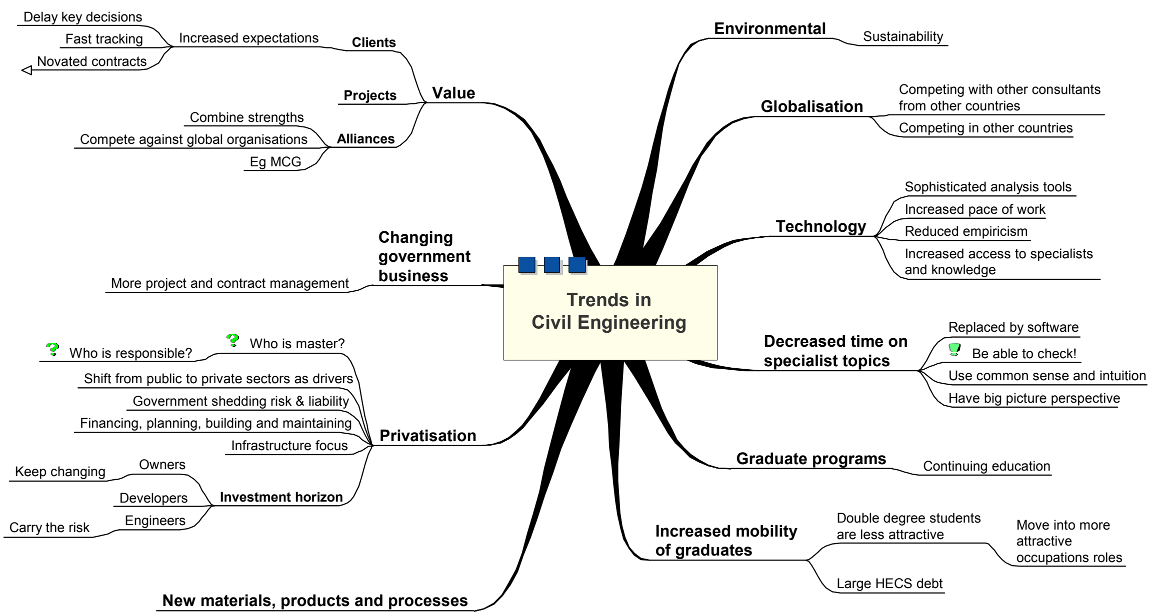
This paper has described the redesign of the civil engineering program as civil and infrastructure program for introduction in Feb 2004. The key changes in the redesign have been:

- Identification of *graduate capabilities* as the focus of student learning.
- A focus on the *whole lifecycle* of an infrastructure facility, rather than on detailed design.
- Use of *sustainability principles* as key to decision making for civil engineers.
- Creation of a stream of *Engineering Practice* courses to provide integration of the content in each semester.
- Recognition of *team teaching* as an essential ingredient in integrating the curriculum around the Engineering Practice courses.
- Use of *team-based, project-based learning* plus *year themes* as means to develop graduate capabilities in a staged approach across the four years.

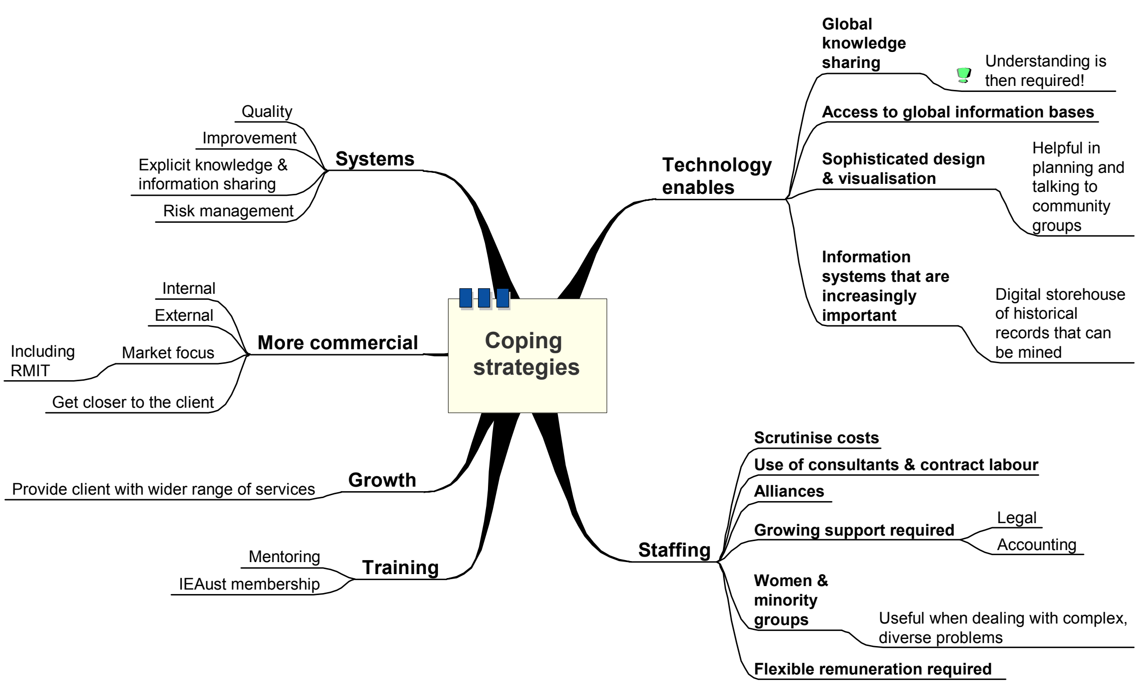
Appendix

Detailed feedback from stakeholder consultation.

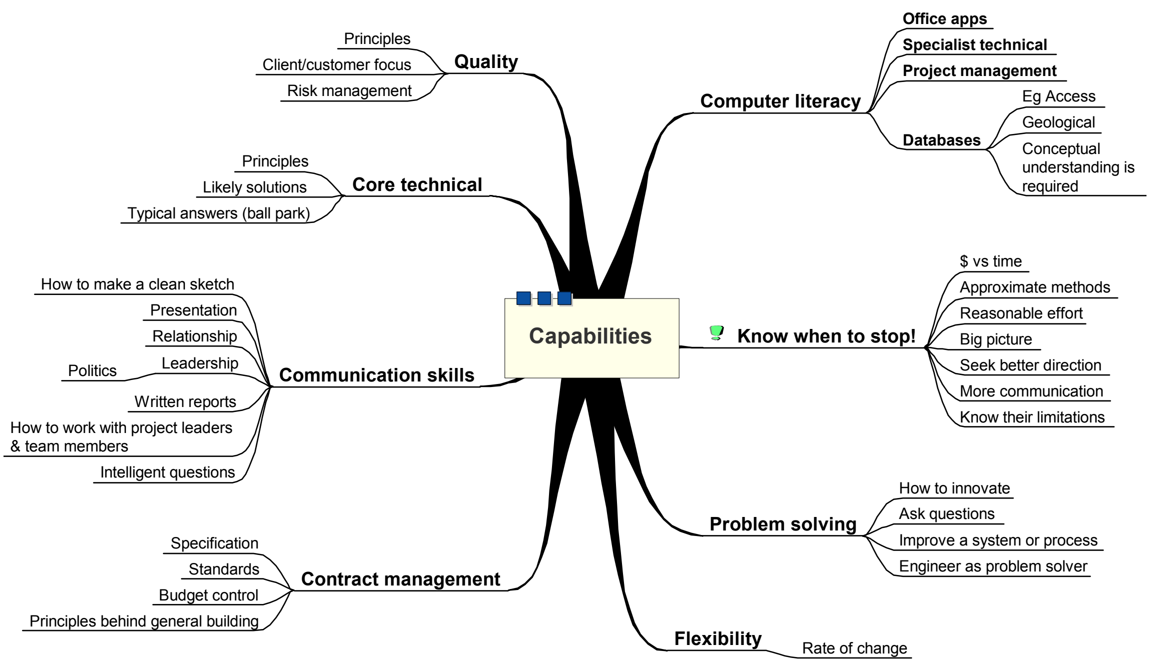
What are the *emerging trends* in the environment that are impacting your organization?



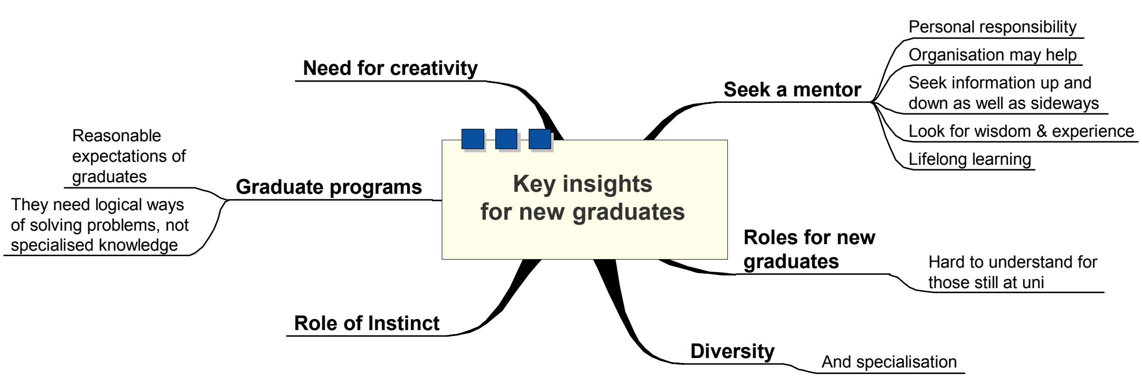
How are you, and your organisation, *dealing/coping* with the pressures to survive and thrive?



What *capabilities* will employees, specifically, graduate engineers, require if they are to effectively contribute to their work organisations and communities into the 21st Century?



What can or should be done to ensure that these young engineers are *better prepared* to meet the demands in their lives as professionals and citizens?



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