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Innovations in Engineering Education

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outline

- innovation is what engineers do
- positioning engineers and engineering thinking
- the Washington Accord – a good innovation
- five ‘historic ‘shifts’ in engineering education, plus two
- current demands on engineering education
- authenticity though innovation
  - engineering practice and engineering thinking
  - best practice student centred pedagogies
  - improving assessment
  - using the Internet – a disruptive technology
  - engineering faculty (organisation and people)
- conclusions – towards 2030

innovation is what engineers do

- translating an idea into a product, process or service that creates value, *that is*
- replicable, and satisfies a specific need
- involves deliberate application of information, imagination and initiative
- is likely to a risk for the organisation
- two broad categories:
  - evolutionary – from many incremental advances in technology or processes
  - revolutionary, discontinuous, disruptive and transformational

Summarised from http://www.businessdictionary.com/definition/innovation.html

positioning engineering

"Engineering [practice] draws on scientific, mathematical and technological knowledge and methods to design and implement physical and information-based products, systems and services that address human needs, safely and reliably. Engineering takes into account economic, environmental, social and aesthetic factors."

"Engineering needs to be applied to [local, national and global] economic, environmental, health and security challenges."

"Engineering research is essential to leadership in technological innovation."

"Every engineering project is different"

"Engineering is achieved by teams, including professional engineers, engineering technologist, technicians and tradespersons"

engineering thinking is "multi-dimensional optimisation" around "sustainability"

technical

maximise energy efficiency

minimise materials use

maximise materials recovery and reuse

maximise subsystem reuse

contextual

minimise environmental impact

maximise human benefit (individual / social)

maximise cost efficiency (over product life)

applies and develops best-practice science, mathematics and technologies

applies and develops best-practice codes, standards and tools

'formative' engineering education

- preparation to enter engineering practice
- turns 'student engineers' into 'graduate engineers' with Washington/Sydney/Dublin Accord graduate attributes

Knowledge-oriented

1: Using engineering knowledge

Defined Knowledge Profile

Problem-solving Skill Group

2: Problem analysis

3: Design/development of solutions

4: Investigations

Defined Level of Problem Solving

Skill-oriented Group

5: Modern Tool Usage

9: Individual and teamwork

10: Communication

11: Project/Engineering Management

Attitude-oriented Group

6: The Engineer in Society

7: Environment and Sustainability

8: Ethics

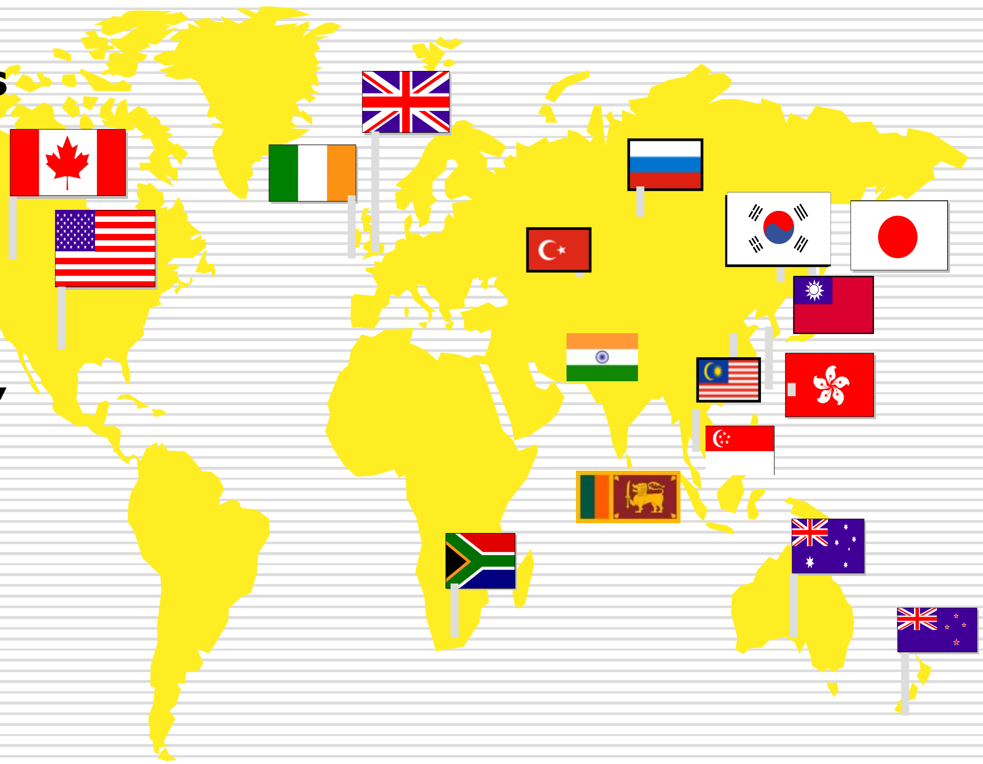
12: Life long learning

globally referenced program accreditation

- Washington Accord Graduate Attribute 'exemplar', implemented in national accreditation systems is:
  - valued by signatories and aspirants
  - valued by universities with accredited programs
  - valued by graduates from accredited programs
  - valued by employers, who may influence local standards and benefit from the implicit graduate benchmarking
- is a successful innovation for ensuring – and raising – global engineering graduate standards
- accreditation should be part of the educational quality improvement process
  - as a collaborative (and critical) activity of the accrediting agency, the faculties and the academics

Washington Accord 1989-2014

- from 6 – 17 Signatories
- tough admission process
- prov members: China, Bangladesh, Pakistan Philippines, Peru
- WFEO 'aspirant' level
- peer-reviews of accreditation 'processes' and 'compliance' with graduate attribute exemplar'
- Signatories 'recognise' others' programs as equivalent to their own
- protocols for cross-border accreditation
- potential links to ENAEE and EUR-ACE labels to Cycle 1 and Cycle 2 accredited programs



international benchmarking' raises the bar'

Girisha Hosanagara Nagarajegowda at the 2012 Paralympic Games in London, clinching silver

How will he perform in 2016?

What will engineering education look like in 2030 in terms of scope, content and delivery?

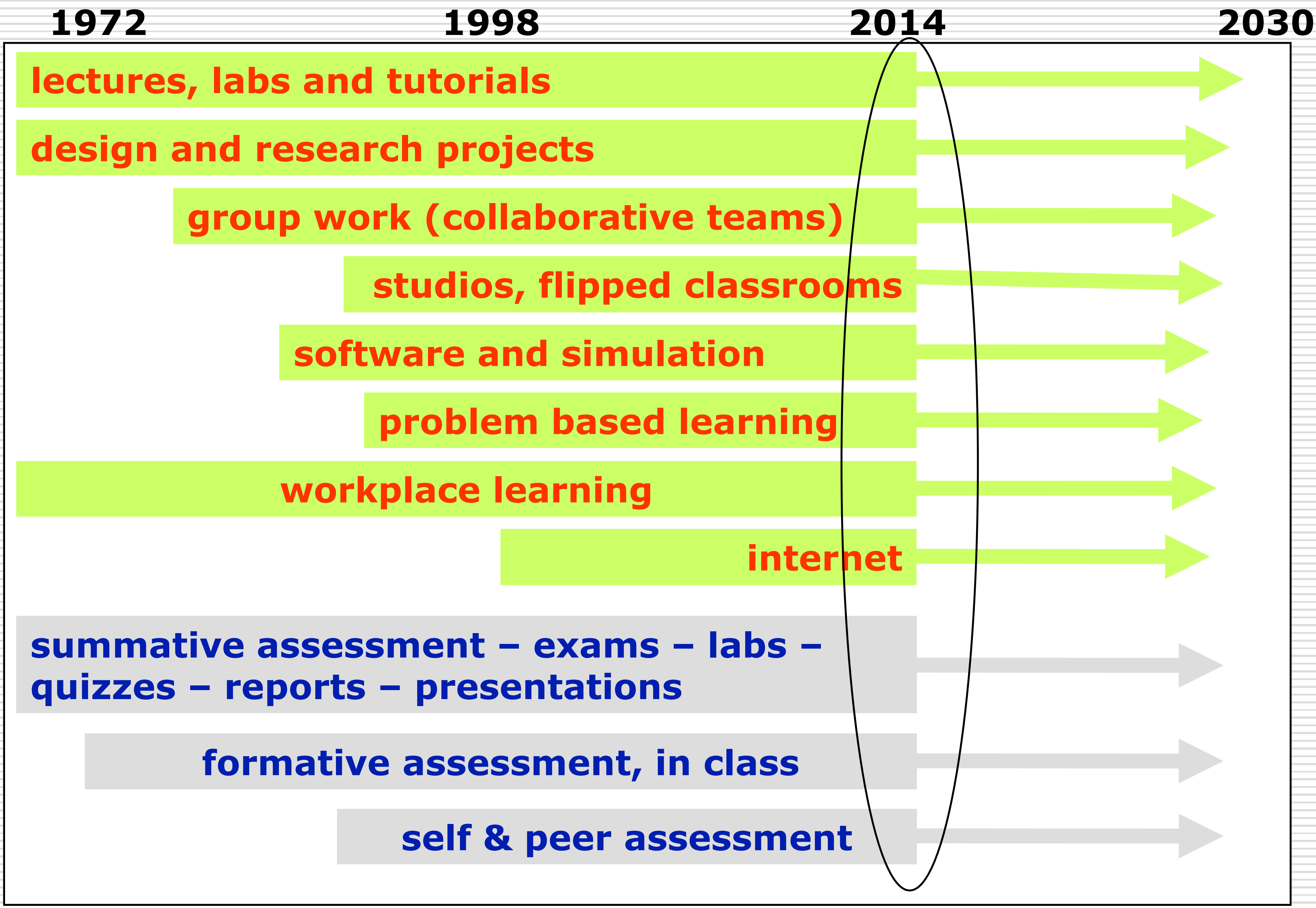
How will it have got there?

five historic shifts in engineering education

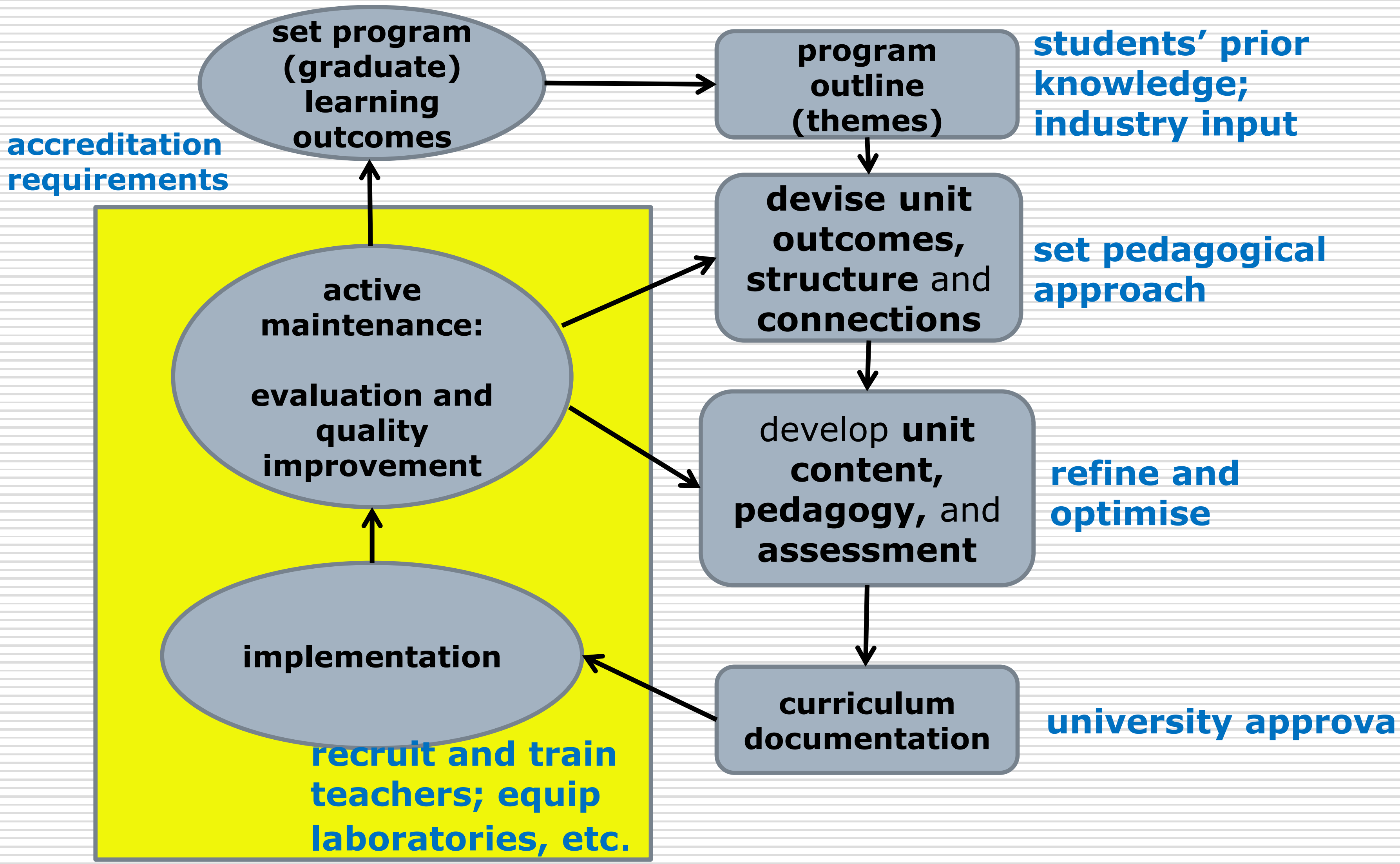
1. From **hands-on practice to science and analysis** (1935-65)
2. Integrating **ICT** into teaching (from 1960s, now disruptive)
3. Emphasising **engineering design** (from 1970's)
4. Emphasising **outcomes, and outcomes-based accreditation** (from 1990s)
5. Applying **education research** (from 1990s), leading to increased use of **problem-based learning**

J Froyd, P Wankat and K Smith,
IEEE Proceedings, 2012

teaching and assessment methods



plus using an engineering approach for education design and implementation (CDIO)



plus 'organic growth' of new engineering areas

specialisations and new connections within and outside engineering, reflect new science, employer needs and students' interests, eg:

- **biomedical engineering**
- **mechatronics and robotics – advanced manufacturing**
- **environmental**
- **software**
- **sustainable energy**
- **photonics**
- **nanotechnology, biomaterials**
- **computational engineering , bioinformatics**
- **geo-engineering**
- **…**

observations on current curriculum

- good recognition of the value of outcomes focus
- partly student-centred – increasing use of problem, project and design activities and group work
- some use of educational IT
- some integration between mathematics and science and engineering sciences
- but tends to have
  - content overload
  - poor links to engineering practice and societal contexts
  - poor quality assessment
  - low attractiveness to women
  - relatively high attrition

drivers for curriculum change and innovation

- **pressures on content and focus** – as above
- **employer pressures – ‘job readiness’ – expects**
  - communication skills, teamwork and project management
  - innovation skills – creativity and entrepreneurship
  - codes and standards, complex risk assessment
  - new technologies
  - performance (eg. measurement) of graduate outcomes
- **academic / institution / education system pressures**
  - balance between ‘education’ and ‘training’
  - high costs of academic staff and laboratory resources
  - ‘publish or perish’ – the rise of research-based rankings – results in less focus on engineering practice and impact
- **student expectations and preferred learning**

how should we address these challenges ?

- possible structural changes for 'diversity'
  - technical and functional
  - depth of problems at graduate and senior levels
- increasing authenticity in the curriculum by
  - more engineering practice and engineering thinking
  - using best-practice student-centred pedagogies

"Industry-based problems come with several unknowns. They are rarely neat packages. Authentic engineering problems give students the experience to work on real-world issues without the simplistic or unthinking application of familiar (textbook) solutions."
Sheppard et al, 2008

- developing authentic engineering faculty

structural changes ?

- should the professional engineering qualification become "a 5-year Masters" degree, as in Europe ?
  - parity with other professions (architecture, law, medicine …)
  - alignment of Washington Accord and ENAEE – Cycle 2
  - but potentially increased costs
- if most graduate engineering work doesn't engage all of the contextual factors in the PE specification
  - develop the 3 – 4 year engineering degree for "being an engineer' especially in technical work
  - with later career articulation/education to PE
  - *management of the perception of such a transition will be very challenging in most countries*

authentic engineering education

- has clarity of purpose (eg graduate attributes)
  - translated to program and unit target outcomes
- embodies engineering thinking and engineering practice
  - through active learning and "work integrated learning"
- focusses on student learning and assessment of target outcomes
- is designed and delivered by 'authentic academics' who use current proven educational methods and resources
  - and advance the art and science of engineering education
- has stakeholder engagement and benchmarking to ensure it is *"the best it can be with the resources available"*
- is formally accredited by an external agency

rate your engineering curriculum and faculty

- How well do the programs / faculties / you are involved with stand up against this model?
  - develop a self-assessment tool against each of these areas
- Can you identify national or international best-practice in each of these areas ?

identify active learning methods – eg from the WA definition of complex engineering activities

- involve the use of diverse resources (people, money, materials, equipment, information and technologies)

  projects – real and simulations – interdisciplinary teams

- require resolution of significant problems arising from interactions between wide-ranging or conflicting technical, engineering or other issues

  problems drawn from industry – case-studies

- involve creative use of engineering principles and research-based knowledge in novel ways

  investigative studies and projects

- have significant consequences in a range of contexts, characterised by difficulty of and mitigation

  case-studies and interdisciplinary perspectives

- may extend beyond previous experiences by applying principles-based approaches

  the core of professional education based on fundamentals

sample of a faculty reflection tool

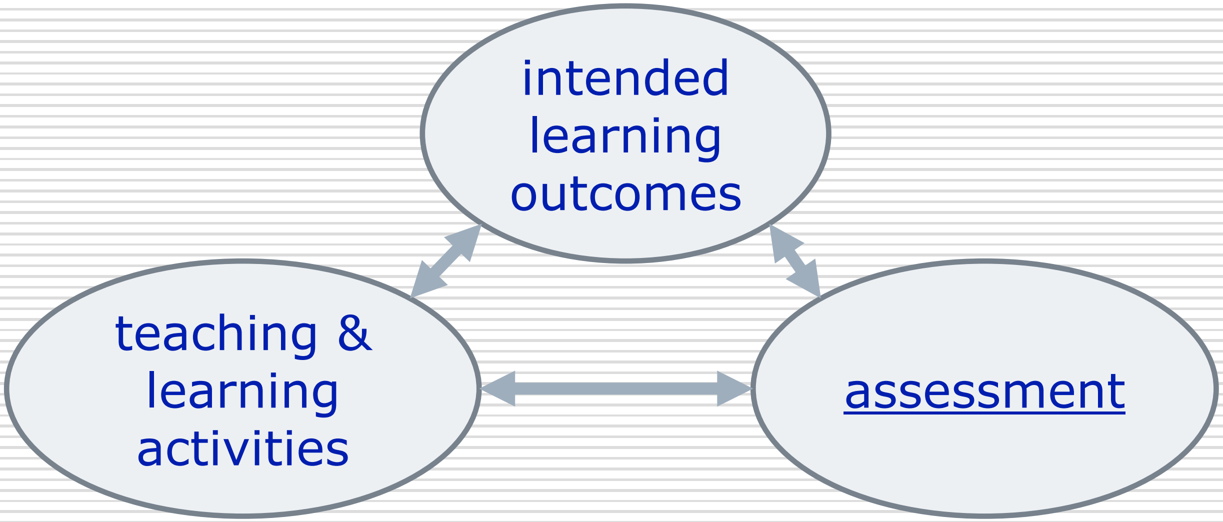
	Hardly at all 1	2	3	4	Extensively 5
Q20 Curriculum Theme 1b. Curriculum delivery includes a range of experiences of engineering practice, positioning theory in its application contexts, by using industry-based examples and projects; and by site visits and guest lectures or similar.	❍	❍	❍	❍	❍
Sample indicators (optional)					
21. Industry based assignments are used in units.	❍	❍	❍	❍	❍
21. Students complete the required workplace experience (possibly in research workplaces) before finishing their coursework.	❍	❍	❍	❍	❍
21. Students undertake industry-based final year projects.	❍	❍	❍	❍	❍
21. Students engage in emulated work integrated learning (e.g. virtual processing plants, miniature plants, manufacturing facilities).	❍	❍	❍	❍	❍
21. Students use contemporary standard industry tools.	❍	❍	❍	❍	❍
21. Students are encouraged and supported to take opportunities to learn about practice (e.g. to visit sites, attend seminars at Engineers Australia, interview engineers, meet with an industry-based mentor).	❍	❍	❍	❍	❍
21. Students are supported to engage with industry through student societies and competitions (e.g. IEEE student branches, motorsports).	❍	❍	❍	❍	❍

authentic engineering thinking and engineering practice in the curriculum

- **from the first year**
  - introduce “engineering thinking” that demonstrate the scope and potential of engineering
  - open-ended, cross-disciplinary, group project work guided by engineering practitioners (eg Engineers Without Borders)
- **middle years**
  - bring industry-inspired whole-class projects into the curriculum to illustrate hard science and practice-oriented topics
  - use group projects with industry support to develop technical knowhow and to develop and assess group working (members and leadership)
  - 3 month industry internship assessed against specific elements (eg design practice, innovation, project management …)
- **final year**
  - individual research/design project with technical focus
  - assess explicitly the reflection on engineering project /thinking

authentic best-practice pedagogies

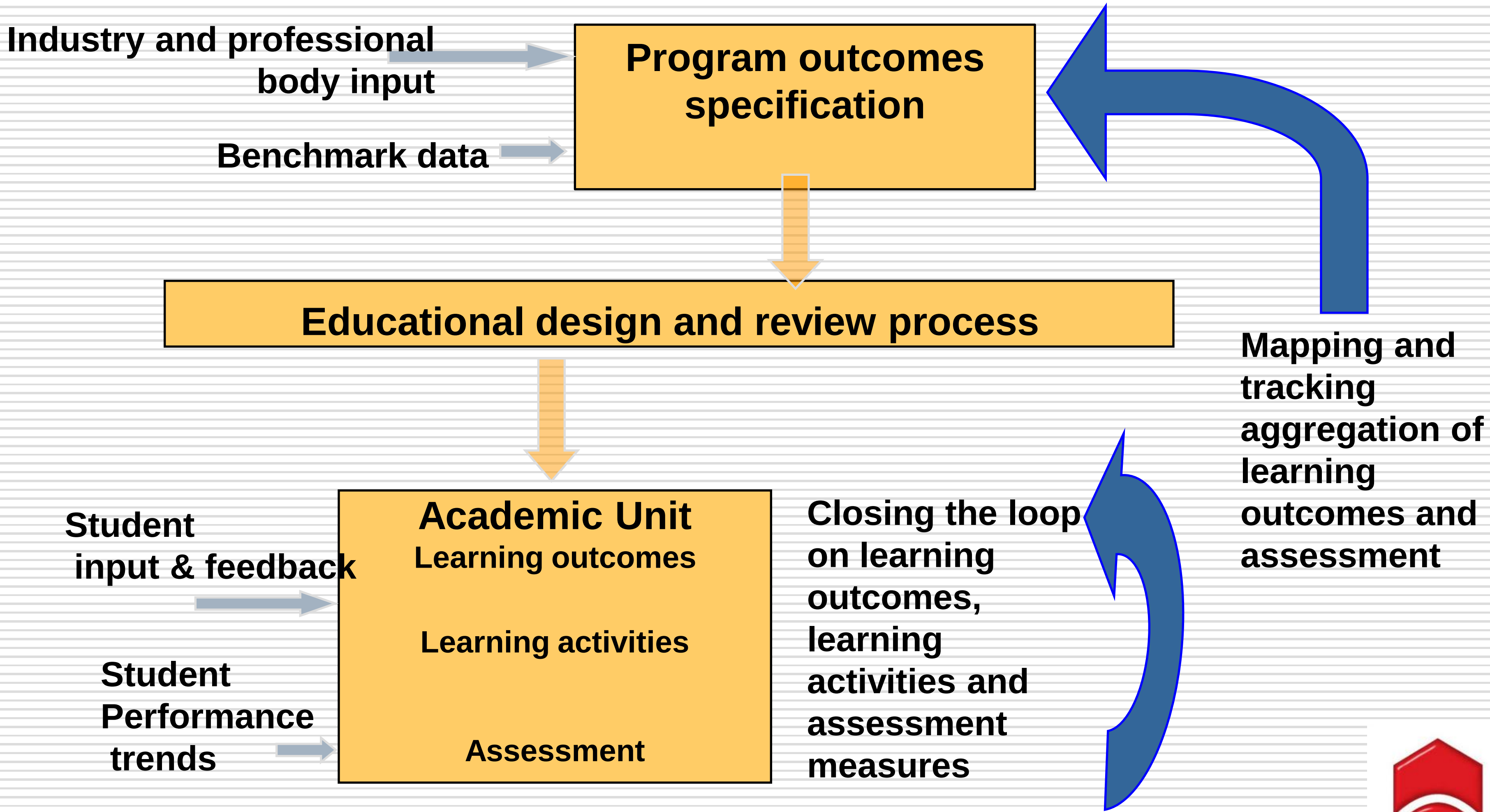
- use the principle of constructive alignment



Biggs and Tang, Teaching for Quality Learning at University (4th ed. 2011)

- **identify and map Unit ILOs to program learning outcomes, for**
- **choose suitable active and authentic content and teaching methods (pedagogy), using Blooms' or SOLO taxonomies**
- **align assessment tasks with ILOs**

aligning unit and program outcomes



ENGINEERS AUSTRALIA

unit alignments in a faculty database

AERO1400: Introduction to Aircraft Construction and Design (2014 - Semester 2)

Download UoS Outline

Overview | Handbook | Teaching | Attributes | Learning Outcomes | Assessment | Schedule | Course Map

Learning outcomes are the key abilities and knowledge that will be assessed in this unit. They are listed according to the course goal supported by each. See Assessment Tab for details how each outcome is assessed.

Design (Level 1)

1. Understanding of the concepts of aircraft configuration and its influence on flight performance.

Engineering/IT Specialisation (Level 2)

2. Skills obtained through hands-on construction experience of aircraft components.

Information Seeking (Level 2)

3. Ability to use information resources, including technical research papers, to understand the aircraft design process.

Communication (Level 2)

4. Ability to create presentations for assignment submissions and to discuss and present information obtained via homework tasks
5. Ability to maintain a clear record of practical work completed through freehand sketches and descriptions in a logbook.

Professional Conduct (Level 2)

6. Familiarity with aviation regulations which promotes the safe design, manufacture and operation of aircraft.

Project Management and Team Skills (Level 2)

7. Ability to work as a team member to complete the progressive assembly of a kitplane.
8. Being able to complete the given task on schedule.

http://cusp.sydney.edu.au/students/view-unit-page/alpha/AERO1400

use the global expertise and literature on engineering education practice

- linking engineering practice to engineering education (inc. CDIO)
- developing engineering thinking and creativity
- students' learning styles, use of social media
- turning (useless) lectures into flipped classrooms
- threshold concept learning
- effective problem- and project- based learning
- using simulations and immersive visualisation
- improved learning spaces for collaborative work
- improving assessment, including self-and peer assessment tools
- engineering design with industry-based projects
- distance learning, including remote laboratories
- introducing sustainability
- understanding and reducing attrition
- pathways from technician to degrees (for working professionals)
- (minority) inclusive curricula and women in engineering

we know good education practice – but need to apply it

improving assessment (of learning)

- exams are used more for ranking than assisting learning
- good assessment (+ feedback) encourages students to achieve learning outcomes, and build confidence
- 3- hour individual exams are not authentic to engineering tasks (but dominate assessment)
- higher level learning outcomes are not as well covered as most educators think they are

- tools and systems for external assessment of learning outcomes have been trialled and are in development by educational agencies (AHELO)

coverage assessments is inadequate

Table 2: Revised Bloom's Taxonomy (Anderson and Krathwohl, 2001)

The Knowledge Dimension	The Cognitive Process Dimension					
	1. Remember	2. Understand	3. Apply	4. Analyse	5. Evaluate	6. Create
A) Factual Knowledge						
B) Conceptual Knowledge						
C) Procedural Knowledge						
D) Metacognitive Knowledge						

Exams

Assignments

All most never

Metacognitive knowledge: awareness of learning and learning strategies, techniques to improve learning, knowledge of one's own abilities and weaknesses, ability to recognise higher and lower level thinking

so choose the best assessment method

- Examination – mostly recall, some analysis, minimal synthesis (time pressure)
- Multiple choice test – recognition/recall, test strategies, comprehension, coverage
- Problem sets – comprehension, technique development
- Laboratory Report – focus, technique, analysis
- Group assignment – information seeking, context, understanding, analysis, argument, negotiation, leadership, teamwork
- Design report – analysis, synthesis, techniques, evaluation
- Journal – reflection, evidence of deep understanding
- Presentation – communication skills
- Concept map – relationships, coverage

- **All methods should have clear criteria and rubrics**

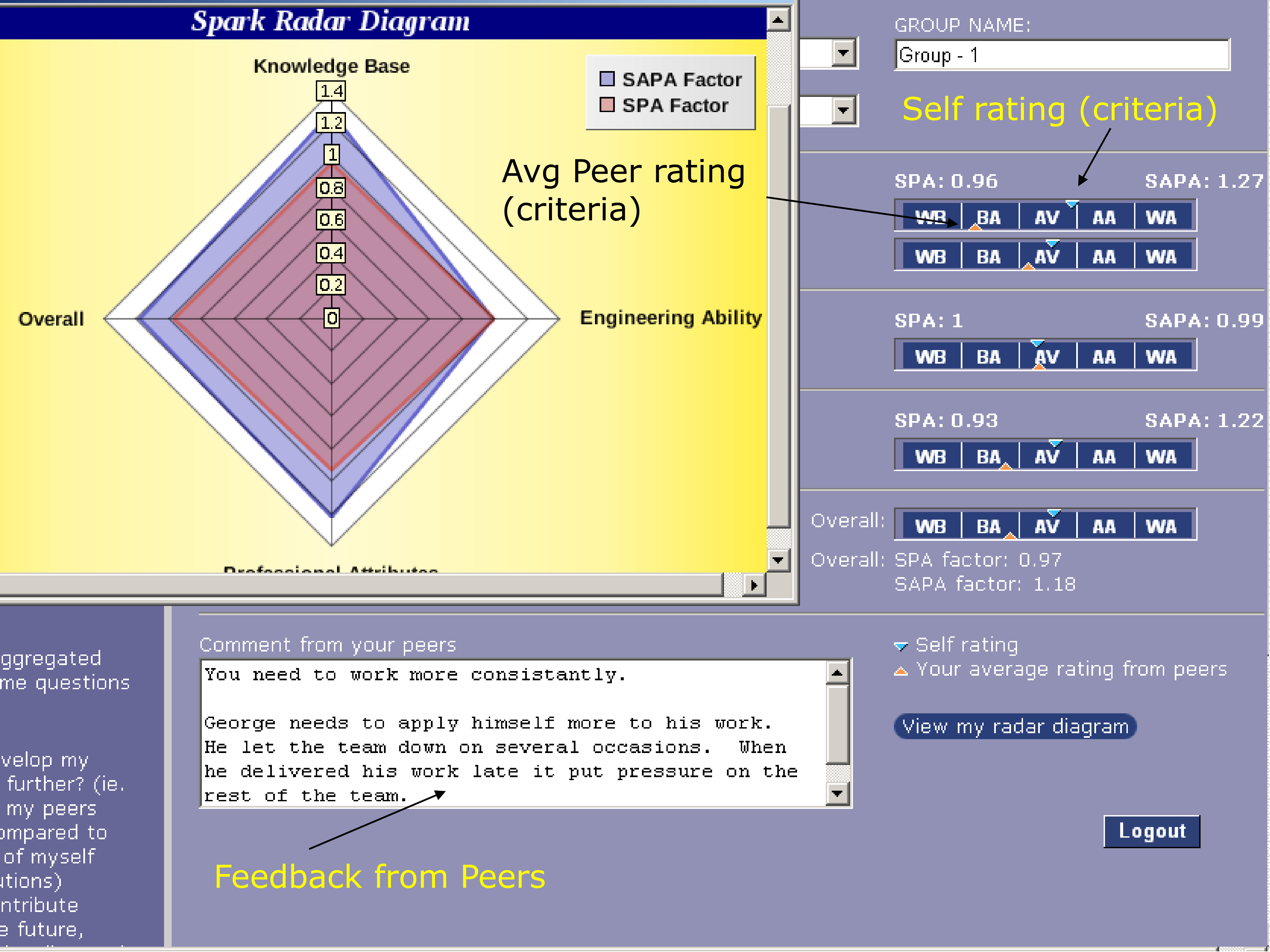
(after Biggs and Tang)

self and peer assessment: validates group work

- learning-oriented assessment - more valuable than assessment only for grading
- group assessment for grading – often regarded as low validity
- engineering students do not (typically) self-reflect, or like making accountable judgments on other students
- group design work is good pedagogy - we need reliable learning-oriented assessment with learner-oriented feedback
- an Australian development is SPARK^{PLUS}
  - provides support for individual and group assessment
  - tutor moderation and benchmarking between groups
  - confidential "feed-forward" to group members
  - demonstrates emergence of different views on same topic

individual assessment by peers

Dr Keith Willey
University of Technology Sydney
National ALTC Teaching Fellow 2011
http://spark.uts.edu.au/



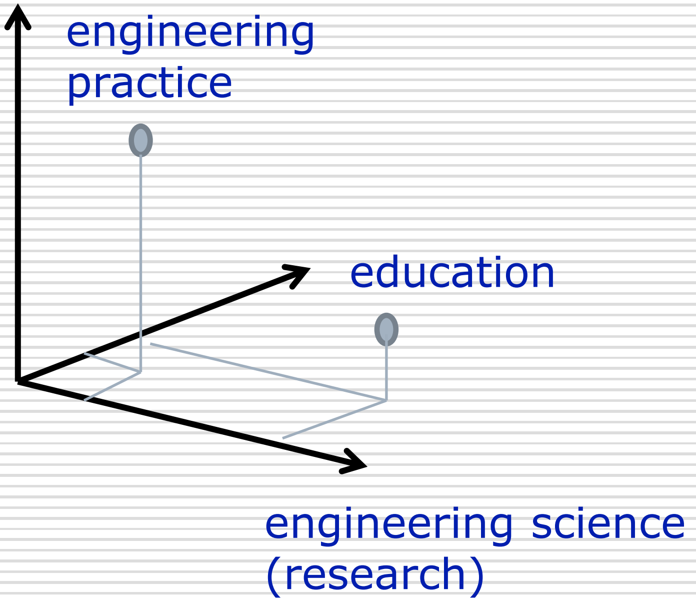
Spark Radar Diagram
Knowledge Base
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Overall
Engineering Ability
SAPA Factor
SPA Factor
Avg Peer rating (criteria)
GROUP NAME:
Group - 1
Self rating (criteria)
SPA: 0.96
SAPA: 1.27
WB BA AV AA WA
WB BA AV AA WA
SPA: 1
SAPA: 0.99
WB BA AV AA WA
SPA: 0.93
SAPA: 1.22
WB BA AV AA WA
Overall:
WB BA AV AA WA
Overall: SPA factor: 0.97
SAPA factor: 1.18
Comment from your peers
You need to work more consistantly.
George needs to apply himself more to his work. He let the team down on several occasions. When he delivered his work late it put pressure on the rest of the team.
Self rating
Your average rating from peers
View my radar diagram
Logout
Feedback from Peers

the Internet will be increasingly disruptive

- fragmentation of curriculum design, content, delivery and assessment
  - ‘content’ is freely available but not classified for integrity
  - one designed curriculum can be delivered and assessed in multiple/different locations
  - MOOCs are being developed and used by reputable universities
- the Internet of machines and big data
  - support technical, management and educational processes
  - make remote laboratories authentic (with practice)
  - all graduates will need to be educated in these transformations
  - automated assessment may be more reliable than human
- beyond content - the educator must be the expert guide and assessors of students on their learning journeys
- accreditation agencies must also respond

authentic engineering educators

- know engineering science **and** engineering education
- have allocated time and support for
  - training (eg Grad Cert. qualification) in engineering education
  - annual professional development in engineering education tools and techniques
  - engaging with engineering practice
  - engaging with engineering education research
  - innovative teaching
  - publishing and networking
- operate above threshold levels in 3-D expertise space
  - and are recognised, rewarded and promoted for 3-D performance



the authentic engineering faculty

- has a balanced profile of educators in this 3-D space
- has systems and experts for supporting education design, teaching and assessment
- has full professors in engineering education
- has a doctoral school for engineering education research
- is involved in national / international networking for engineering education improvement
- is supported by a national body (‘Office for Learning & Teaching’) for university teaching and learning improvement, to fund
  - fellowships, projects and programs
  - (can be a low cost, but vulnerable innovation)

conclusions – potential areas for innovation

- **engineering occupations and entry level qualifications**
  - **diversity will continue to grow (to respond to need)**
  - **more 'Masters' level courses (technical and functional)**
  - **restructuring the basic degree may be needed ... *and will need consideration within ...***
- **the international accreditation system**
  - **should retain 'substantial equivalence' principles**
  - **needs to be responsive to internationalisation of education**
  - **more interworking between IEA and Europe**
- **international education networks**
  - **CDIO will continue to grow**
  - **conference and 'communities of practice' networks will be strengthened through the Internet**

conclusions - potential areas for innovation

- **the curriculum will become more authentic**
  - **improved engagement with engineering practice (including research and innovation)**
  - **programs will include more engineering focussed multi/extra-disciplinary content**
  - **teaching and learning methods will be better chosen and delivered – fewer lectures, more flipped classrooms, more projects and more integration with employment**
  - **improved assessment will promote learning - more self-reflection and more authentic group assessment**

- **academics will share more support resources and tools**
  - **managing groups and projects; self- and peer- assessment**
  - **managing industrial experience (work integrated learning)**
  - **using curriculum mapping tools**
  - **understanding attrition (via cohort analysis)**

conclusions - potential areas for innovation

- academics will share more educational resources
  - knowledge-based teaching materials
  - project materials
  - assessment materials
- some faculties/schools will specialise more strongly
  - teaching focussed – e.g. production of high quality resources for MOOCs and BOOCs (‘boutique’ small enrolments, high cost)
- engineering education becomes a genuine area for engineering practice, encouraged by faculties, universities and engineering organisations
  - a school’s academics have defined expertise levels, eg
  - 20% undertake research-driven teaching
  - + 60% do innovative teaching
  - + 20% are competent teachers at a tested threshold level

conclusion

- strong community need for more and better engineering graduates – and we have sound education and accreditation systems
- we have sound educator base, and growing communities of practice for improving education
- we face significant challenges in providing education of high quality and manageable costs
- using technology well and educational research will lead to effective educational innovations
- so let’s work together to make these happen

- Thank You

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Washington Accord Graduate Attributes (1 - 5)

Graduate Attribute	Description
engineering knowledge	**Apply knowledge** of mathematics, science and engineering fundamentals and an engineering specialisation to the solution of **complex** engineering problems.
problem analysis	**Identify, formulate, research** literature and **analyse complex** problems reaching substantiated conclusions using first principles of mathematics, natural and engineering sciences.
design/solution development	**Design** solutions for complex engineering problem and design systems, components or processes that meet specified needs with appropriate consideration of public health and safety, cultural, societal and environmental considerations.
investigation	**Conduct investigations** of **complex** problems using research-based knowledge and methods, including design of experiments, analysis and interpretation of data and synthesis of information …
modern tool usage	**Create, select and apply** appropriate techniques, resources and modern engineering and IT tools, including prediction and modelling, to **complex** engineering activities, with an understanding of the limitations.

Washington Accord Graduate Attributes (6-12)

Attribute	Description
the engineer in society	**Apply reasoning** informed by contextual knowledge to assess societal, health, safety , legal and cultural issues and consequent responsibilities relevant to professional engineering practice …
environment & sustainability	**Understand** and evaluate the sustainability and impact of professional engineering work in the solution of complex engineering problems in societal and environmental contexts.
ethics	**Apply** ethical principles and commit to professional ethics and responsibilities and norms of engineering practice.
individual & teamwork	**Function effectively** as an individual, and as a member or leader of diverse teams and in multi-disciplinary settings.
communication skills	**Communicate effectively** on complex engineering activities with the engineering community and society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations and give and receive clear instructions.
project management & finance	**Demonstrate knowledge and understanding** of engineering management principles and **apply** these to ones' own work, as a member or leader in a team, to manage projects and in multi-disciplinary environments.
lifelong learning	**Recognise** the need for, and have the preparation and **ability** to engage in independent life-long learning in the broadest context of technological change.

Range of Complex Engineering Problem Solving

Complex engineering problems cannot be resolved without in-depth engineering knowledge, much of which is at, or informed by, the forefront of the professional discipline, and have one or more of the following characteristics.
• involve wide ranging of conflicting technical, engineering and other issues
• have no obvious solution and require abstract thinking, [and] originality in analysis to formulate suitable models
• require research-based knowledge … informed by practice at the forefront of the discipline … allows a fundamentals-based, first principles analytical approach
• involve infrequently encountered issues
• are outside coverage of standards and codes of practice for professional engineering
• involve diverse groups of stakeholders with widely varying needs
• have significant consequences in a range of contexts,
• are at high level, including many component parts or sub-problems