It's time for a coordinated approach to computer-aided learning and assessment

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Abstract*: There are significant pressures on higher education in Australia: continually reducing funding per student in real terms, an exponential growth in the knowledge base and growth in complexity of the problems that engineers face. Students need more project work to allow them to develop real engineering expertise (as opposed to engineering knowledge and skills). Project-based learning is aided by ready access to good online materials that can help students acquire basic skills and that will allow them to test their basic competency. It's time that we shared these learning resources across the sector (both nationally and internationally). Specifically, we should identify existing good online materials and make them readily available. We should develop, if necessary, good online assessment so that students can test their skills at any time, without waiting for end of semester exams.*

The global context

There are some interesting things happening in higher education at the moment. We have ridden the wave of specialisation in engineering through the second half of the 20th century inspired by a more rigorous, scientific approach to engineering. Yet, we are now confronted by global problems for which we have the scientific tools (eg global climate models) but for which we lack the social skills to make much impact (politicians choose sub-optimal solutions such as desalination plants). Several studies have recommended more broadly educated engineers to cope with problems that stretch our minds in four dimensions – the technical, the social, the environmental and the economic (National Academy of Engineering 2004),(Spinks, Silburn et al. 2006).

> *… engineering firms look for skills and attributes in two broad areas. The first is a set of defining skills that are unique to the engineer and which encompass the domain of technical skills. These include a sound knowledge of the engineering fundamentals within their discipline, built on a solid base of mathematics. Other highly sought-after attributes in this domain are creativity and innovation plus the ability to apply theory in practice. The second skill set includes the social and interpersonal skills and attributes that enable the engineer to operate in a commercial working environment. These include communication skills, team-working skills, and business skills, which for entry-level graduates primarily mean awareness of the commercial implications of engineering decisions.* (Spinks, Silburn et al. 2006)

The introduction of the (University of) Melbourne Model is one initiative to meet this breadth plus depth requirement. It provides a broad foundation for university education, with students taking a major discipline as well as a minor in a non-cognate discipline (the breadth sequence). It also provides an opportunity to bring the teaching of separate engineering disciplines closer together as we move into a world requiring interdisciplinarity and sustainability.

Some of the key elements of the Melbourne Model are (The University of Melbourne 2007):

- Depth and breadth, a major sequence and a minor one
- Capstone studies: translating knowledge into experience through projects
- Knowledge Transfer: connecting students, employers and the community

- Creating global citizens through an international experience

New engineering education

From the student perspective, we have been told by our students that "engineering is to be endured rather than enjoyed". This is in marked contrast to practising engineers who would say that engineering is inherently interesting and challenging. How can we make learning engineering as interesting and challenging as engineering practice? How do we take students along the path from novice to expert, acknowledging that it takes more than just theories to develop expertise? (Atherton 2003)

We need a new model of engineering education. We have pursued the lecture plus tutorial model about as far as it will go. Students are turning away from our lectures in droves; they're simply too boring. This is the iPod iBlog iGoogle generation, at ease with instant access to information 24/7/52 (Boyd). They need more flexible ways of learning and demonstrating engineering expertise.

All of this needs to happen within a university research environment. Either, we see teaching as a major distraction from research time or we see the undergraduate and postgraduate students as a part of our team, who will contribute to our research agenda.

A conceptual model

Figure 1 shows a simple model of curriculum design. The key stages are:

- Identify professional **needs**
- Define learning **outcomes** (to deliver the needs)
- Create learning **activities** (that match the intended outcomes)
- Identify learning **resources** (that help students with the activities)
- **Assess** the learning outcomes
- **Evaluate** the learning process. What needs to change?

> if students are to learn desired outcomes in a reasonably effective manner, then the teacher's fundamental task is to **get students to engage in learning activities** that are likely to result in their achieving these outcomes, taking into account factors such as prior knowledge, the context in which the material is presented,… it is helpful to remember that what the student does is actually more important in determining what is learned than what the teacher does. (Shuell 1986) (my emphasis)

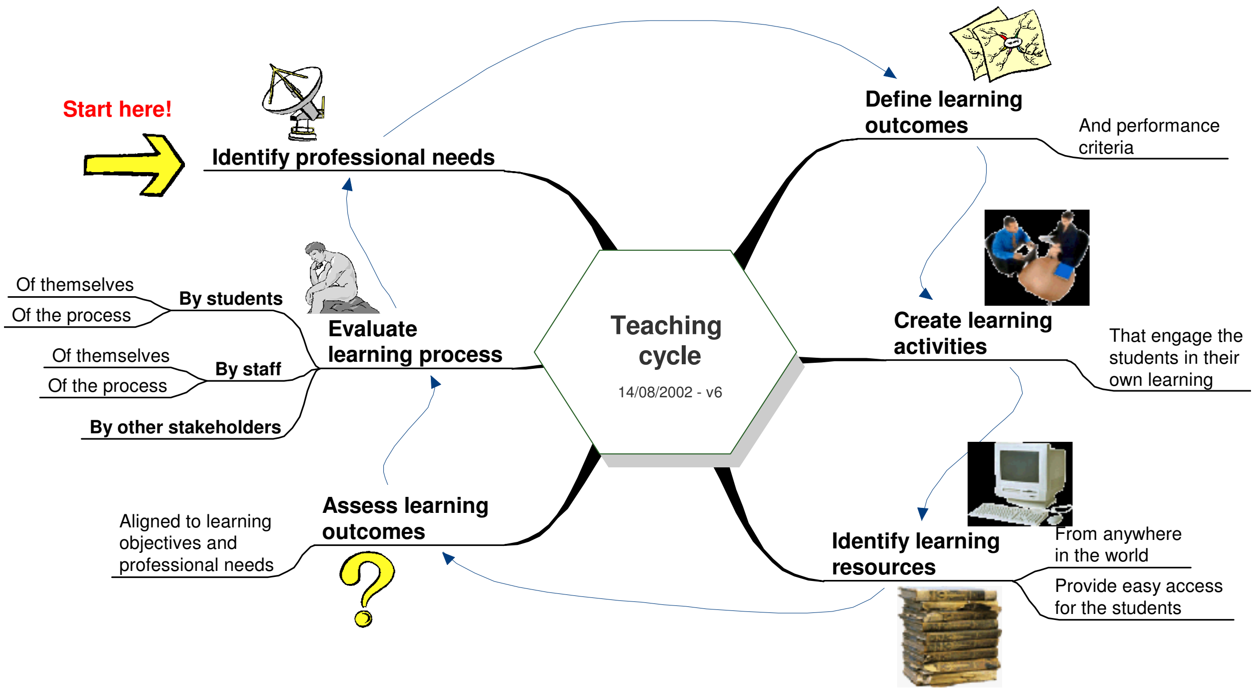

Figure 1 - A curriculum development cycle

A key focus here is on the **learning activities** to deliver the learning outcomes. The traditional focus has been on writing a list of topics and skills to be learned, often stripped bare of the context in which the knowledge or skills will be applied.

So, we should focus on the **problems** that students will solve in tutorials. How will these problems develop the learning objectives/outcomes? What do I expect students to be able to **do** by the end of the semester? Yet, we spend more time on our PowerPoint slides. Our role should be to get students working on the tutorial exercises and assignment problems.

Professional practice

The engineering method is the use of *heuristics* to cause the *best change* in a *poorly understood* situation within the *available resources* (Koen 2003).

As we grapple with more complex problems, it is even more obvious that we must teach the professional practice of engineering (which includes the practice of engineering research). Students will then understand:

- The *lifecycle* of engineering artefacts and the roles of engineers from strategic planning through design and construction and operation to decommissioning and recycling
- The *engineering method* that guides their work (Figure 2)
- The range of *graduate attributes* that underpin this engineering method (Engineers Australia 2004).

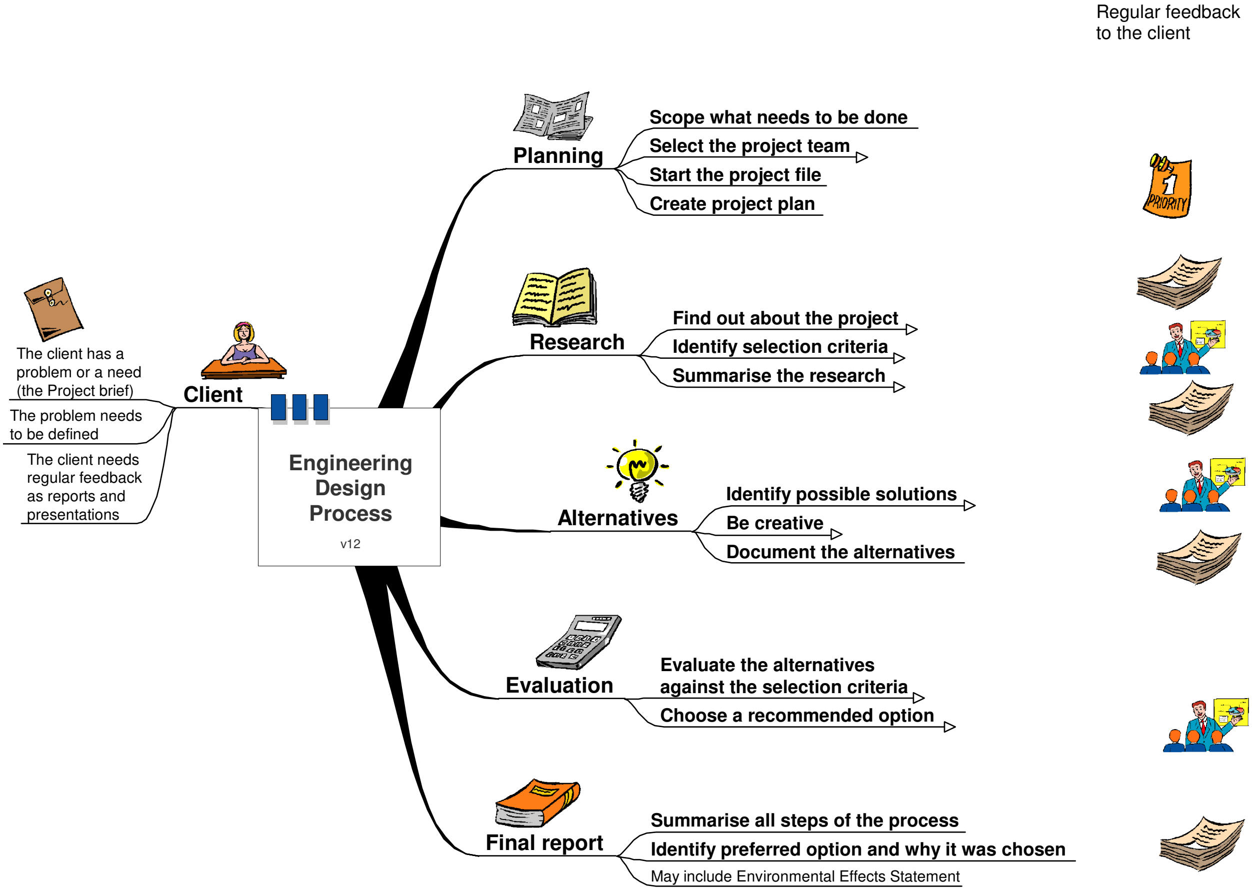

Figure 2 - An Engineering Method

Students will learn engineering practice through project work – structured engineering practice that starts small in first year and builds to independent and interdependent, large projects in final year (Hadgraft and Grundy 1998). These projects will develop the full range of graduate attributes, demonstrate the use of the engineering method and cover the lifecycle of engineering projects as summarised in the CDIO initiative: conceive, design, implement and operate (CDIO).

One of the interesting aspects of Figure 2 is that it becomes quickly obvious to students that *communication* is an essential aspect of engineering work – communicating with colleagues in teams and with the client in oral, written and graphical forms.

Another aspect that emerged in our experience is that an emphasis on communication can also improve other aspects such as the quality of research that is done to support the problem solving (Goricanec, Hadgraft et al. 2005). First year students were required to write *briefing papers* on topics to inform other group members. This exercised their writing skills, encouraged them to do the required investigation, brought home the importance of correct citing and referencing and built a platform of knowledge for the group problem solving. A later query showed that this skill was absent in final year design teams, where there was no real attempt to document what the team knew. As projects become larger and more complex, such documentation processes are critical to their success.

Skills & Projects, Delivery & Competence

Engaging students in the engineering design process (or problem solving in general) will require more project work than we have been used to deliver. Within these projects, students will be expected to acquire new skills. This moves project-based learning closer to the original intent of *problem-based learning*, where the problem drives the learning of new knowledge and skills (Hadgraft and Paget 1990).

A simple model divides the curriculum between skill acquisition and project work:

Skill acquisition – mostly computer-based skill development combined with computer-based assessment. Students progress at their own pace and are likely to progress faster than they do at present (Smialek 2005). These online activities could be supported by tutorials and drop-in classes.	**Projects** – engineering practice. This can be thought of as studio-based learning. Students must have passed the relevant modules to be admitted to the project. Some of these will be design tasks, eg the SAE Formula racing team; others will be research. Some will be community service such as Engineers Without Borders or industry projects. The whole engineering lifecycle should be represented.

There is a need to move from a focus on skill building to a focus on complex problem solving. Students need to be able to see how to apply engineering techniques in complex, real world situations and they need a lot of practice at this, because it is often different every time. Examples include: water supply for cities impacted reduced reservoir inflows caused by global warming, water supply and sanitation in developing nations, transport in megacities, global trade imbalances, sustainable energy, etc. These are the problems that the next generation of engineers will face. We need to equip them with the capabilities required.

Of course, students also need to be able to easily learn new skills, because otherwise they try to keep applying only a limited range of skills when a new skill or insight is needed. "Every task looks like a nail if the only tool you have is a hammer". This is the essence of lifelong learning.

So, students need to be able to move from the project task to skill development and back again (Figure 3). This matches the situation they will find themselves in industry, where new ideas are required and there is past experience from which to draw.

At the moment, skill development is mostly confined to lectures and tutorials, but there are good online systems also available (see below), which need to be more widely advertised and adopted. These need to be supported by *online assessment* so that students can develop skills at their own pace and test themselves to make sure they've got it right. This aspect is still poorly developed, with most of the emphasis to date on delivery of content rather than on its assessment.

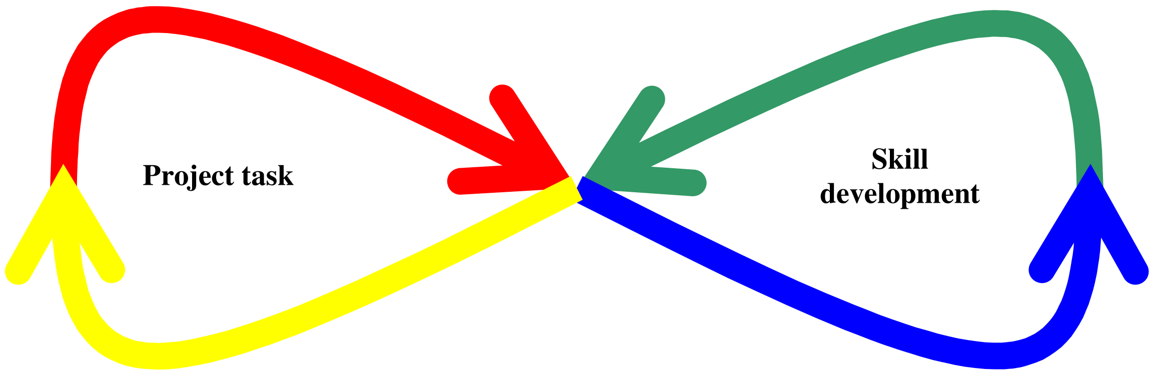

Figure 3 - Modelling task plus Skill development

Verification of computer-based assessment will be done under exam conditions, but not necessarily in the traditional exam period. Students will have a record of their competence in their **e-portfolio**. A discussion of some of the issues around widespread introduction of an e-portfolio is available (Harper 2007).

Many students will complete more than the minimum set of modules because they will complete the work more quickly, eg (Rutz, Eckart et al. 2003),(Knowledge Dynamics 2004). This will free up time for staff to create and conduct more complex learning situations for students – the project-based component of the curriculum.

Beyond Skills

As students gain more skill and work on more complex problems, there are two more loops that become important, namely *learning from others* and *learning from the literature*. The first relies on the fact that there is someone else who knows how to solve this type of problem. The student's role is to find that person and learn from them. This is very common in the workplace (Smith 2004).

The second method is just a variant of the first except that rather than talking to a colleague, the student/graduate must trawl the literature to see how others have solved this problem. Now we have a four-bladed propeller (Figure 4). The hub of the propeller is the student's abilities to switch learning modes to suit the situation. This model borrows from Latour's model of creating change (Latour 1999),(Hadgraft and Goricanec 2007).

Our role as educators is to give all students enough experience at each of these four modes of learning so that they learn the ability to switch from one to another.

Projects

The project task drives the learning. Problem based learning methods (Landsberger 2007) provide the strategy for solving problems and are a variant of the engineering method (Figure 2):

1. Explore the issues
2. List "What do we know?"
3. Write the problem statement in your own words
4. List possible solutions. If possible, choose a preferred solution (and jump to step 7).
5. List "What do we need to know?" Where are our knowledge gaps?
6. Who will do which parts of the additional research? (project management)

   (At the next meeting) return to step 2 with new information. This may alter the problem statement and the range of possible solutions.

7. Document your solution
8. Review your performance

As educators, it is our responsibility to give students a structured set of projects over their period at university to develop their project skills, their specific engineering skills, their collaborative learning skills and their research (literature) skills and their confidence with each of these. These project tasks are, in my experience, fundamentally *more interesting* because they deal with real, complex problems and students can (or should be able to) see the importance of the application.

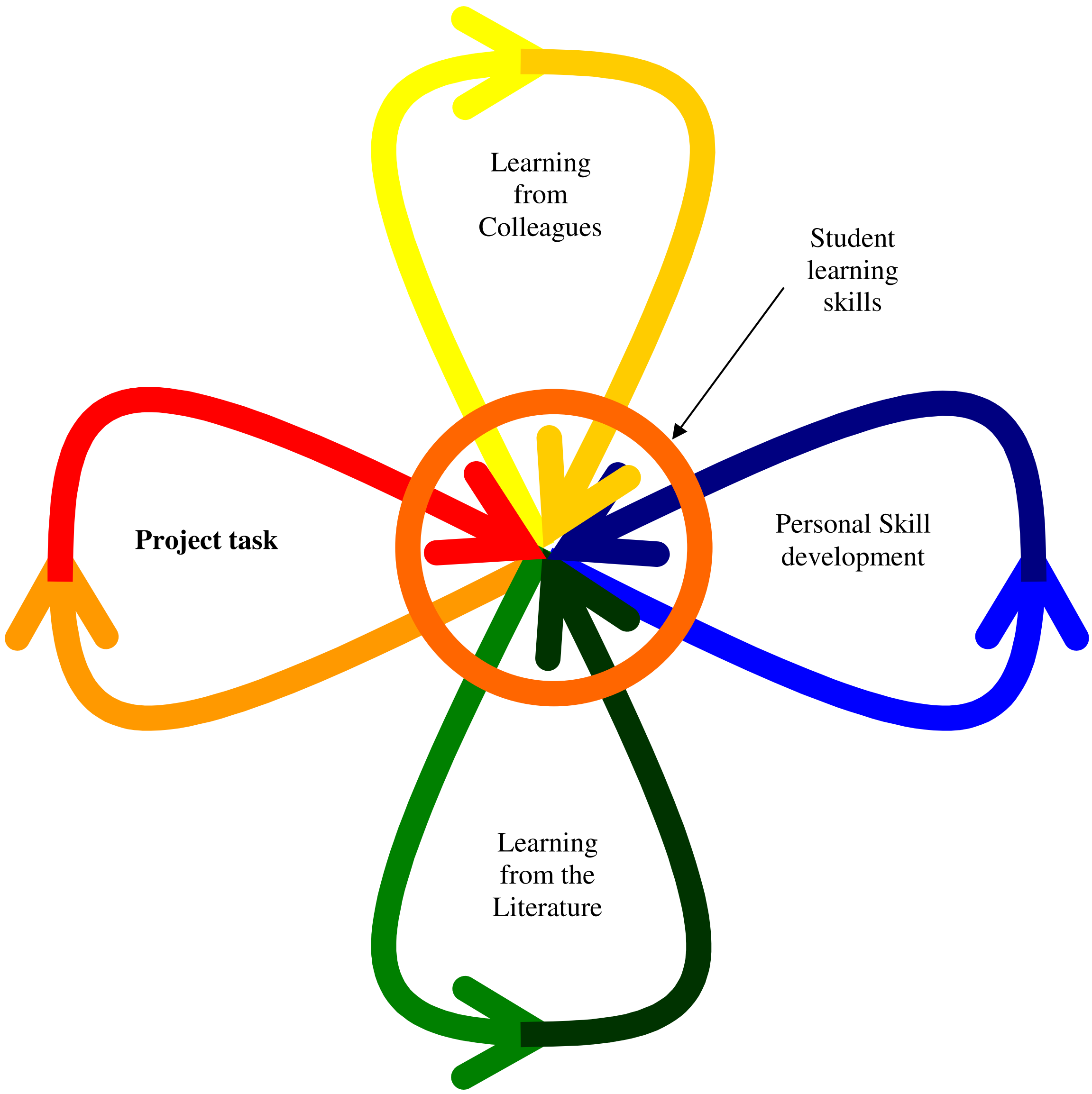

Figure 4 - Modelling plus Skills development plus Learning from others plus Learning from the Literature

Back to Skills – an Example

Consider Statics as an example of one of the core study areas where students of many engineering disciplines need to develop some basic skills in order to engage in more complex (and interesting) project work. An online survey has revealed the following navigator or directory sites (Table 1) where many resources for Statics and other topic areas can be found. These include online tutorials, e-books, research papers and (a little) online assessment.

Table 1 - Key directories for engineering education resources

Directories	Title and URL	Comments
Univ. of Maryland	HAMLET – directory to statics, dynamics and mechanics of materials http://www.eng.umd.edu/HAMLET/resources.htm	Great place to start for online resources for mechanics.
MERLOT	Engineering – General	A range of basic engineering

Directories	Title and URL	Comments
http://www.merlot.org	http://www.merlot.org/merlot/materials.htm?category=2661	materials. Probably the most extensive collection.
Engineering Pathway	http://www.engineeringpathway.com	Part of National Science Digital Library http://www.nsdl.org. Another extensive site.
Foundation Coalition	http://www.foundationcoalition.org/	Focus on first and second years and curriculum integration
Gateway Coalition	http://www.gatewaycoalition.org	A range of modules and virtual labs
CDIO	http://www.cdio.org	A particular approach to teaching engineering practice
NEEDS	http://www.needs.org	Registration required. Search the library.
SUCCEED	http://succeednow.org	
UK Engineering Subject Centre	http://www.engsc.ac.uk/	Limited resources for statics
World Lecture Hall	http://web.austin.utexas.edu/wlh/	Some online subjects.

Exploring these sites has revealed a range of resources for learning Statics (Table 2). There is surprisingly little in terms of assessment of the skills, although there is some self-assessment material.

Table 2 - Individual sites for learning Statics

Site	URL	Comment
Buffalo	Interactive Structures http://www.aia.org/SiteObjects/files/Vassigh_color.pdf	Structures for architects and designers
Carnegie-Mellon	Statics http://www.cmu.edu/oli/courses/enter_statics.html	Part of CMU's Open Learning Initiative.
Educative Technologies	Structural mechanics – eWorkbooks and self-assessment http://www.educativetechnologies.net/	Self assessment in beams, frames, trusses, machines
Iowa State	Statics http://bits.me.berkeley.edu/cw/00/02/36/1/static.exe	Authorware
John Hopkins	Truss designer http://www.jhu.edu/~virtlab/bridge/truss.htm	Web-based software
Missouri-Rolla	Engineering Mechanics http://web.umr.edu/~oci/index.html	Statics & dynamics
	MecMovies - Mechanics of Materials http://web.umr.edu/~mecmovie/index.html	Basics to combined stress states
Missouri State	Virtual Laboratory for Structural Mechanics http://www.ae.msstate.edu/vlsm/	
MIT	Engineering Mechanics of Solids http://ocw.mit.edu/OcwWeb/Civil-and-Environmental-Engineering/1-050Fall-2004/CourseHome/index.htm	
Nebraska, Lincoln	Mechanics Source page http://em-ntserver.unl.edu/	Statics, dynamics, mechanics of materials; supporting maths
Ohio	Statics http://www.ent.ohiou.edu/~statics/	
Oklahoma	Fundamentals of Engineering Review (statics, dynamics, mechanics, materials, thermo, fluids, maths, economics, ethics, electrical, computers, chemistry) http://www.feexam.ou.edu/ OU Engineering Media Lab http://www.ecourses.ou.edu/	

Site	URL	Comment
Purdue	Statics http://www.engr.iupui.edu/~zecher/soft.html	Downloadable multimedia
Rochester	Statics interactive tutorials http://www.rit.edu/~pnveme/plig_2004/Statics/	
South Carolina	Engineering Mechanics http://www.gatewaycoalition.org/files/Engineering_Mechanics/index.html	Text & graphics
Virginia Tech	Engineering Applets http://www.engapplets.vt.edu/	Statics, dynamics, fluids, .etc

Among these resources, there are excellent online materials for all engineering students to access. The next task is to create a series of online questions as the basis for assessment. Some work has been commenced in this area at the University of Melbourne. Collaborators are welcome, with the intention of seeking national funding for the project of assembling suitable online tutorials with robust online assessment.

e-Portfolios, Evaluation and Knowledge Management

In an experiential learning system, students will need to track their learning achievements in both the online modules and also in the projects. Engineers Australia has provided a framework through the Stage 1 Competency Standards (Engineers Australia 2004) for mapping competency development. This is an extensive summary of the non-technical skills that young engineers should be able to demonstrate. A similar list is required for the technical skills, which will be matched against the online modules (and assessment) discussed above.

Students and staff will keep logbooks to track their performance and the performance of the system. That is, they will take a research approach to teaching and learning – Action Research (Dick 1997). What can we be doing better? Since this is now a resource-based approach rather than a person-based approach, it is a system easier to improve by buying or developing better resources, most of which will be online.

This new learning system will be backed up by a *knowledge management system,* not a learning management system. Both students and staff will contribute to improving the available learning resources. A current example is the use of a wiki where students contribute to the improvement of the lecture materials (course notes) as well as contribute their own research papers as lecture extensions (Tribe 2007).

Large engineering organisations are global entities. They rely on knowledge management systems (KMS) to share knowledge across countries and across time zones. Specifically, these systems comprise:

- Document repositories, eg past designs and reports, company standards, contracts, emails, etc.
- Special interest groups (of people) on particular topics, accessible through specialised forums and via email for more private communication.

In their project work, students need access to this full range of knowledge. We will evolve our current learning management systems into *knowledge management systems* so that all of our people, staff and students, can learn from each other and all can contribute to this growing body of knowledge. Current work with wikis is a step in this direction.

Planning

We now need to properly map the curriculum in each engineering discipline according to the model described earlier (Figure 1):

- What are the professional needs? What **expertise** is required?
- What are the required learning **outcomes** to match? What should students be able to DO at the end of each subject?
- What learning **activities** are appropriate to help students develop the expertise?
- What **resources** are required to support students as they complete these activities? What resources already exist, with a focus on online delivery and assessment? What allies can we engage in the further development of these?

- How will we **evaluate** our success and make improvements?

This planning will be an important stage in a funding request to begin to build an online resource for the learning of engineering that will have two major components:

A database of suitable **project** case studies, ready to run.	A set of **online modules** for skill development to support the projects, with robust assessment processes.

Conclusion

We now have 20 years experience in project-based learning and computer-assisted learning. However, we have made little progress in properly integrating these two strategies. Nor have we made much progress in successfully pooling our resources so that our teaching is more efficient. Our classes look little different than what they did 20 years ago, apart from students downloading our PowerPoint slides (which we all insist on writing for ourselves. The pressures to do more with less are increasing. If we are to work smarter, we need to pool our resources.

It's time that we developed a coherent approach to computer-assisted learning and assessment, so that students can learn the basic skills at a time to suit themselves and we can spend our time working with students *beyond the basics* in professionally relevant project work to develop real engineering expertise.

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