AC 2008-1332: COMPUTER-AIDED LEARNING AND ASSESSMENT: THE NATURAL PARTNER FOR PROJECT-BASED LEARNING

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Roger Hadgraft is a civil engineer with more than 15 years involvement in engineering education research. He has published many papers on engineering education, with a particular focus on problem/project-based learning and the use of technology to support learning in this way. He was instrumental in introducing a project-based curriculum into civil engineering at Monash University, commencing in 1998. From 2002-6, his work at RMIT was in curriculum renewal to embed graduate capabilities, specifically through a stream of project-based courses/subjects, one in each semester of the four year programs in civil, chemical and environmental engineering. He has consulted on PBL to several Universities, nationally and internationally. Roger has been a member of the Australasian Association for Engineering Education (AAEE) Executive since 2001 and is its President in 2008. In February 2007, Roger was appointed at the University of Melbourne as Director of the Engineering Learning Unit to assist in the introduction of the new Melbourne Model in engineering, to support new project-based learning courses and new learning spaces and to improve teaching quality across the School of Engineering.

Computer-aided learning and assessment: the natural partner for project-based learning

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 ^{1, 2, 3, 4}.

The introduction of the (University of) Melbourne Model is one initiative to meet this breadth plus depth requirement ^{5, 6}. The Melbourne Model 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. This approach has been supported also in the USA ^{7, 8, 9}.

New engineering education

From the student perspective, we have been told by our students that “engineering (at university) 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? ¹⁰

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; lectures are simply too boring. This is the iPod iBlog iGoogle generation, at ease with instant

access to information 24/7/52¹¹. 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.

Focus on learning activity

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.¹²
(my emphasis)

We need to focus on the **learning activities** to deliver the learning outcomes. The traditional focus has been on writing a list of topics 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 and design projects.

Professional practice

The engineering method is the use of *heuristics* to cause the *best change* in a *poorly understood* situation within the *available resources*¹³.

As we grapple with more complex problems, it is even more obvious that we must teach the professional practice of engineering (which should include 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
- The range of *graduate attributes* that underpin this engineering method^{14, 2}.

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^{15, 16}. 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 operate¹⁷.

One of the interesting aspects of the engineering method 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

solving¹⁸. 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 skills¹⁹.

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

<p>Projects – engineering practice. This can be thought of as studio-based learning.</p> <p>Students must have passed the relevant modules to be admitted to the project.</p> <p>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.</p>	<p>Skill acquisition – increasingly computer-based skill development combined with computer-based assessment.</p> <p>Students progress at their own pace and are likely to progress faster than they do at present²⁰.</p> <p>These online activities could be supported by tutorials and drop-in classes.</p>
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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 by reduced reservoir inflows caused by global warming, water supply and sanitation in developing nations with limited resources, 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. Students will also tackle these problems within a global workforce, where they work on engineering teams spread across the globe²¹.

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 1). 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 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 1 - 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 ²².

Many students will complete more than the minimum set of modules because they will complete the work more quickly, eg ^{23, 24}. This will free up time for staff to create and conduct more complex learning situations for students – the project-based component of the curriculum.

Projects

The project task drives the learning. Problem based learning methods ²⁵ provide the strategy for solving problems and are a variant of the engineering method ²⁶:

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.

Resources available

What online resources exist to help in this process? There is a series of navigator or directory sites (Table 1) where many resources for all branches of engineering can be found. These include online tutorials, e-books, research papers and (a little) online assessment, as well as links to companies, data and various other documents.

Table 1 - Key directories for engineering education resources

Directories	URL	Comments
National Science Digital Library	http://www.nsdlib.org .	542,703 results for “engineering”.
Engineering Pathway	http://www.engineeringpathway.com http://www.engineeringpathway.com/ep/community/eng.html	9,075 results for “engineering”. Engineering Disciplinary Community Pages
MERLOT	http://www.merlot.org/merlot/materials.htm?category=2661 (Engineering)	517 results for “engineering”.
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
NEEDS	http://www.needs.org	Registration required. Search the library.
SUCCEED	http://succeednow.org	
UK Engineering Subject Centre	http://www.engsc.ac.uk/	55 results for “civil engineering”
World Lecture Hall	http://web.austin.utexas.edu/wlh/	Some online subjects.
More specialised directories ...		
CDIO	http://www.cdio.org	A particular approach to teaching engineering design practice
Geotechnical, Rock and Water Resources Library	http://www.grow.arizona.edu/	865 resources on 16 Jan 2008
HAMLET, Univ. of Maryland	http://www.eng.umd.edu/HAMLET/resources.htm	Great place to start for online resources for basic mechanics.
MIT Open Courseware	http://ocw.mit.edu	Click on “Engineering”
More general-purpose directories ...		
Virtual Library	http://vlib.org/Engineering	
Intute: science, engineering & technology	http://www.intute.ac.uk/sciences/engineering/	Good overview and tour of web resources for engineering

Exploring these sites has revealed a range of resources for learning basic structural engineering, as one example (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 structural engineering

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.umsr.edu/~oci/index.html	Statics & dynamics
	MecMovies - Mechanics of Materials http://web.umsr.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 http://www.feexam.ou.edu/	Statics, dynamics, mechanics, materials, thermo, fluids, maths, economics, ethics, electrical, computers, chemistry
	OU Engineering Media Lab http://www.ecourses.ou.edu/	Statics ; Dynamics ; Fluids ; Thermodynamics ; Math - Calculus ; Mechanics ; MEMS ; Multimedia
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

A 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.

Knowledge Management

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. 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 ²⁷.

Planning

We now need to properly map the curriculum in each engineering discipline according to the model described elsewhere ²⁶:

- 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.
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Such a site would be a very different repository from those in Table 1. Rather than a library-like catalogue of many contributions, it will be organised around the capabilities required within each discipline of engineering.

Tracking student progress

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 ¹⁴ 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 would use a planning tool to schedule the completion of the modules they need. An example is shown as Figure 2 from ²⁸:

Figure 2 – Example of student work planning and scheduling tool

Students and staff will keep reflective 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 ²⁹. 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.

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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