Integrating Engineering Education – key attributes of a problem-based learning environment

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Background

I have spent the last 15 years experimenting with problem-based learning in the civil engineering classroom, first at Monash University and now at RMIT [1]. I have applied or assisted other staff in applying PBL in structures, geomechanics, computing, surveying, transport, communications, etc. Students consistently indicate that projects and teamwork are the highlights of their learning experiences. Staff say that they've never had such good questions before. So, why aren't we doing more of it? This paper is a quick review of the issues in implementing project-driven engineering curricula.

Why PBL?

The switch to PBL followed the lead of the medical discipline that recognized as early as the 1960's that the traditional science-based medical curriculum was not producing the sorts of medical practitioners that were required. In fact, by the time many medical students were ready to move into clinical settings they found they had to relearn the basic sciences from earlier years.

Likewise, engineering students often have to relearn their analysis techniques once they get to the stage of doing design. In addition, they find they never use a bunch of things that they learned in earlier years. Why do we waste their time with these things?

There is a touching faith in the idea that you load students with mathematical analysis methods for three years before letting them loose on design. Yet design often only requires quite simple calculation processes. When do we distinguish conceptual design from detailed design?

In the 1970's, it was necessary to load students with complex analysis methods because they had to be able to perform the computational procedures in the design office. Of course, now, we have computer software for that purpose (which is far more sophisticated than you could teach an undergraduate in 4 years).

In the 00's, we still want students to have conceptual understanding, but we do not need them to be able to solve matrix and differential equations. This is more often done for them.

Methodology

What models have we used for these changes?

In an earlier publication [2], a colleague and I identified key attributes of PBL in engineering as:

- Problem – drives the learning
- Integration – helping students see the whole problem rather than individual tools

- Teamwork – getting students working and learning together
- Resources – who is responsible for finding the learning resources – teacher or student?
- Process – a problem-solving process structures the student activity

Earlier papers describe different combinations of these attributes in different sorts of courses and at different levels [3, 4, 5]. Some overall conclusions are:

- Problems are, of course, the essence of engineering.
- Problems can provide different levels of integration by varying the size of the problem. Problems can vary in size from an hour to a semester, or more.
- Problems can be solved in teams or individually, though teams are preferred for most work.
- Students in earlier years usually expect more support from the teacher, who is more likely to organise much of the learning materials. In later years, we could expect students to find their own learning resources.
- Likewise, in earlier years, students need an explicit problem-solving process, whereas in later years they have the confidence to know what to do next.

Examples

To be fair, engineering programs have had elements of these ideas for many years. Final year design courses and research projects most easily fit these ideas.

There are also plenty of examples of the application of these ideas in first year as a means of engaging students in engineering [6]. Engaging first year students in the engineering process is not trivial. We discuss these challenges in another paper at this conference [7].

Can we make it work in the middle years and what might it look like? What are the impediments to such change? Consider these examples.

Once upon a time, students would study three years of structural analysis before they were allowed to do structural design in year 4. At RMIT, we are giving first year students mini design projects (a truss bridge and a cable-supported carport roof).

By second year, we are asking them to design a four storey building frame, first in steel and then in concrete. This gives them practical exposure to both structural theory and design codes. In their geotechnical engineering course in the same semester, they consider footings and excavation for the building. In their construction economics course, they examine the buildings economics. This one project in second year provides integration across the curriculum. (We have not yet implemented integration into the water engineering (pipe flow) and transport engineering courses – parking and traffic flow issues).

In third year, we ask the students to design structures that are more unusual, such as cable-stayed bridges. They also complete the concrete building from year two by designing the floor slabs. In fourth year they are doing design of high rise and long span structures (eg sports stadiums). Conceptual understanding is developed through this project sequence, as it might be as an apprentice in a design office.

The Process

As with the medical students, we are teaching the students to *think* like engineers. They must take the whole problem, pull it apart, understand the analysis methods that they need to use, manage the project, work in teams, etc – all the things they'll need to do in the workplace.

The problem-solving process we are using has a number of key phases [8]:

- The client brief/need – what is required?

- Planning – how will we address the problem in the time available?
- Research and problem definition – finding out more so that we know what we will do and how we will do it
- Alternatives and selection criteria – what solutions are available and how will we choose between them? This phase should have community input in many cases.
- Analyse the alternatives against the criteria.
- Choose one or more preferred options using a formal decision process.
- Make a recommendation and document it.

In this process, only one step requires mathematical analysis processes, yet, in the past, that's where we've put most of our teaching and learning. Now we're trying to help students develop skills in all areas.

Why is this important?

Sustainability and the Future of Engineering

Problems are increasingly complex. They do not have neat solutions. Whereas engineers were once employed to build dams and pipelines, now they are employed to manage water resources. This might require demand management, improving efficiency, eg infrastructure renewal to reduce leaks, water recycling and reuse, etc. Many of the problems are social ones (eg attitudes to water reuse) rather than environmental, economic or technical, even though our graduates are expected to be competent at these as well.

In the context of a building, engineers might need to co-develop an environmentally friendly solution with the architect, making effective use of materials, water, natural ventilation and so on. The building frame will be routinely designed using sophisticated software. The real intellectual input is in the green design. Innovation is required, as is up-to-the-minute research.

Are we preparing our students for this type of design by teaching them matrix methods of structural analysis? How will they learn integrative design? Will this happen magically in the final semester?

Consider other problems that engineers now face:

- Major city tollway of 40 km crossing a dozen suburbs
- Water reuse – shifting treated effluent 200 km for industry users
- Dredging of a shipping channel and its environmental consequences
- Water recycling for urban reuse

These problems assume that the basic technical challenges are easily solved. This is not where the innovation of the future will come from. Likewise, the environmental consequences are quite well understood. This century is much more about the *social impact* of engineering:

- Social opposition to tolls – why doesn't the government pay for this road?
- Social opposition to using treated water for urban (eg drinking) purposes
- Social opposition to unpredictable environmental consequences of large scale dredging
- Social opposition to squandering energy and greenhouse gases on desalination when better management of water resources would be a more effective solution

What sorts of engineers are we trying to produce? Are we to produce technoslaves to perform routine tasks or are we producing *leaders* of society who will generate innovative solutions for tomorrow's increasingly complex problems? If the latter, can we possibly do it by working bottom-up?

Once upon a time we believed that engineering was built on the physical sciences, including mathematics. Now our graduates need to understand ecology, biology, psychology, sociology, etc. These are some of the *new basics*, a term we have borrowed from the Queensland Government [9]. We have discussed the bigger picture elsewhere [10].

Engaging Staff

I have discussed the sorts of projects that can be used to develop students' understanding and to help them to integrate their chosen discipline. How do we engage staff who have taught in traditional ways to move towards this style of teaching and learning?

Looking back on my own experiences, I can only suggest working with those who are already committed, while working with other staff to move slowly in a problem-based direction. The advantage of a mixed curriculum – some problem-based and some traditional courses, makes this possible. The converted staff run the project-based courses and the traditionalists stick to teaching the disciplines. However, even in these courses, it is possible to move the discussion from principles to practice.

For example, in Statics, we teach principles but also have the students build and test a model truss bridge and design a real bridge with real loads. We may not be able to make it truly problem-based, but we can provide integration of the ideas so that students see how the principles are applied in a real project.

An important part of moving staff views is to engage them through teaching teams. The teaching team for a semester gets together to discuss the project course and how it will integrate aspects from the other three courses. Teaching becomes a team process rather than an individual one. Isn't that what we're helping the students to learn? We need to learn it too!

Learning Spaces

Once you move to more collaborative learning, you will need collaborative learning spaces. We have recently refurbished several classrooms with round tables and wireless networking. Students are able to use these spaces outside of scheduled class times. The rooms are also equipped with a PC, VCR/DVD player and projector to display rich learning resources. These facilities are particularly helpful for student presentations.

Technology

Problem-based learning is a natural fit with an environment rich in learning resources. Fortunately, there have been many online tutorials and other resources developed over the last 10-15 years, so that our students can get ready access to some of the best material in the world, eg [11]. Education is no longer limited by access to information, which it may have been 30 years ago. It is now limited by the rate at which we can digest the information that surrounds us.

This suggests that we need to understand something about how we learn (how our brains work).

Another contentious issue is *how* do we assess, *what* do we assess and *when* do we assess it?

How we learn

If you haven't already read Zull's book on how we learn, I strongly suggest it [12]. Two important messages:

- The brain's basic processing cycle
- Physical changes in the brain are required for real learning.

Our brains work through a cycle of Sensing, Integrating (at both concrete and abstract levels) and Acting. This is pretty much how Kolb describes it in his learning cycle [13]. We need to adapt our teaching methods to the way the brain works. Project work is in tune with this process because:

- it starts with sensing (a problem or a need),
- Moves through reflection (what might be suitable solutions? What do we know/not know?),
- To abstraction (how can we analyse the problem?)
- To acting (describing and documenting our solution).

Of course, this same cycle is enacted at every level of the problem solution. Thinking is a fractal activity [14]. It looks the same at every scale of magnification.

Zull's second important message is that we learn by hard wiring our brains. Constant practice reinforces neural connections. This requires our brain cells (neurons) to grow new connections. This is time consuming. If you reflect on anything that you have learned, you will realise that it was very time consuming. It takes practice. Once learned, though it is hard to forget. Jump on a bicycle after 10 years and off you go.

What does this tell us? Learning takes practice, practice, practice! Now, this might seem to be ammunition for the traditionalists who say, "I told you so! Students need to practice the skills". This is true. My experience is that it is difficult to get students to practice solving textbook problems. They are just too boring. However, if they can see them in the larger context, they might be more tolerant to practise the skills. That's why we've put project work and traditional teaching together in each semester. Presenting textbook problems as puzzles might be another engaging route.

Assessment

We have all invested much effort in flexible delivery of course materials. Now we must invest similar effort in *flexible assessment*. Students need to be able to practise their skills and test themselves on typical problems. Likewise, we need to be able to guarantee that they have reached certain performance standards or competencies. We should be able to generate a test at short notice when a student is ready to take it. By graduation, they should have a collection of *competencies* rather than a set of exam marks, which mean very little. In Australia, this approach is standard in TAFE (Technical and Further Education – typically trade qualifications). When will we see it in Higher Education?

Summary – key attributes of a problem-based learning environment

We have roamed around a number of issues in building a problem-based learning environment in engineering. The key factors are:

- Use problems to provide *integration across the curriculum*.
- Engage staff in a way that they can adjust to this new style of learning through a mixture of problem-based and traditional courses. Build teaching teams.
- Engage students in a way that matches how their brains learn (through meaningful practice).
- Change our teaching and learning spaces to suit collaborative, technology assisted learning.
- Make assessment flexible so that it can be taken at almost anytime.

Through this process, we will prepare students to solve the complex, multidisciplinary problems of the future.

I would be delighted to discuss these matters with you further; please contact me at:

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