Providing a Context for First Year Engineering Students: A report on attempts at course inversion

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Abstract: *Observations of how engineering students approach learning activities in the earlier years of their degree, report that they do not recognise real-life context that links to the theory they are required to apply in learning tasks. This impacts on their motivation and contributes to a lack of transfer of basic knowledge in the latter years of their degree. A new subject for first year engineering students was introduced at the University of Wollongong in 2005 focusing on real-life engineering problems requiring analysis for effective solution. Students are encouraged to explore the use of basic principles and available analysis techniques relevant to projects they have to complete. Students' experiences of learning were measured by survey. The results together with a review of learning theory led to adjustments for the subsequent offering. Experience with the implementation of this subject underlines the fact that curriculum innovation does not necessarily lead to immediate success. Time, experience, evaluation and development of theoretical understanding were all important for us in implementing a new approach to teaching.*

Key Words: *Experiential learning, praxis, course inversion, enquiry-based learning*

Our observations and ideas for a solution

Within the context of particularly poor results in engineering mechanics subjects in the second year of the engineering degree at the University of Wollongong, we set out to make changes to our course. After much discussion, the task force that was formed to determine a solution to the problem concluded that we needed to establish a different approach to learning of engineering theory.

Our observations of many past cohorts of students, particularly in their second and subsequent years of study led us to form two conclusions from essentially anecdotal evidence:

1. Students appeared to be essentially assessment driven. Current students seem to spend considerable effort researching the experiences of past students to determine what might be the easiest path to an adequate mark. The literature suggests that students who are assessment driven will study in a way that is most likely to assure their success at assessment time (Wankat and Oreovicz, 1993). For all but the most well designed learning and assessment tasks, this usually means a substantial amount of surface or rote learning (Biggs, 2003).

2. Students reported and displayed a very limited retention of theoretical knowledge from their studies. They appeared not to connect theory taught with problems requiring its use. This apparently limited transfer of basic knowledge is ironic given that engineering degrees have traditionally been structured to build up a theoretical knowledge base, ‘brick-by-brick’, aimed at producing a capability to solve engineering problems. This ‘fundamentals first’ approach, with its lack of early context, has been demonstrated to impact negatively on the learning of some students (Felder and Silverman, 1988; Biggs, 2003), and may also reduce student motivation for learning (Boekaerts, 1986). In the words of one of our student focus group participants ‘you just have to hold your breath until third year’. It may be argued that this knowledge construction work is not explicitly designed by the lecturing staff, let alone conveyed or understood by the students.

Once it was agreed that a context for learning was important to the quality of that learning, analysis of our curriculum at the University of Wollongong led to the conclusion that such a context was not generally provided for students until the latter years of their degree. The main shortfall in our degree structure to be solved was the provision of a context that would overcome the students’ lack of understanding of the relevance of theory taught in earlier years. It was hoped that provision of this context would enhance initial student learning, student motivation and also knowledge retention.

There was also a view that students came to university with a significant existing theoretical and practical knowledge which may not have been viewed in an ‘engineering’ way. If students could connect this knowledge to engineering analysis they would gain confidence and bring their existing knowledge into play. Such a capability to recognise engineering problems and to identify the theory relevant to that problem is a core engineering skill that would require progressive development over the entire degree program.

In response to the problems observed (assessment driven approaches to learning, and disconnect between theory learning and its application in engineering problem solving), we decided to design a new subject that would induct students into their engineering studies with an intensive, contextualised design experience. We developed a subject called ENGG101 Foundations of Engineering.

ENGG101 – round one (2005)

Initial design (2005)

We set out to get student ownership of their learning. We wanted students to feel motivation in ‘more difficult’ subjects (eg. engineering mechanics). It was hoped that learning ‘curiosity’ would be enhanced, and would offset the assessment-driven approach we often observed We also wanted students to see the context for their learning of basic, theoretical concepts.

Armed with our initial anecdotal understanding of the problem, we sought to develop a subject that would introduce students to engineering analysis through confronting them with actual problems (immersive, experiential learning). A course development committee was formed and considerable design effort went into the development of two central projects and some supporting learning activities.

Essentially the subject design effort centred on the development of two projects. These were to be undertaken in succession, each over a five to six week period. These were intended to immerse students in the experience of doing design, prior to learning the theory that underpinned their designs. The first project focused on mechanics and involved the construction of a balsawood beam capable of supporting a known load with a specified deflection (Figure 1). The second project focused on flow processes and involved the construction of a water storage tank that developed a discharge stream trajectory to maximise the capture of the water into a fixed container. (Figure 2).

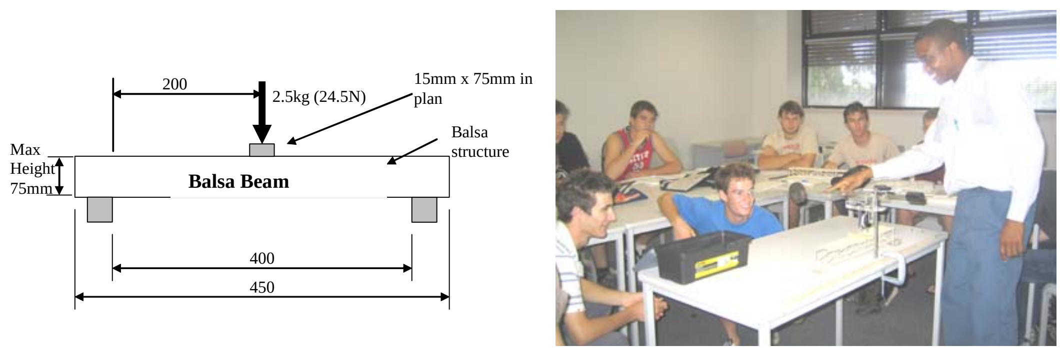

Figure 1: Beam design project.

Figure 2: First attempt at Project 2: Water storage and discharge tank.

For each project, teams of three were self-selected. A specific design problem was set for all groups. The stages of the project were nominally as follows:

Week 1: The groups have a first attempt at solving the problem. Over a two hour period they are required to analyse the problem, develop and then construct a solution. Performance of the solution is measured and compared with the other groups. Testing of each group's solution is followed by discussion on the results.

Week 2: Groups submit a reflection report on the results of their first attempt. The reflection report is assessed.

Weeks 2-5: Groups further develop their analysis, and analytical model, to develop a 'better' solution to the problem. A design report is produced, focusing on the problem attempted in the first week. Lectures and tutorials provide support for students' learning of the theory and application of that theory to the problem at hand. For example deflection formulae and material stiffness are key to the beam design project.

Week 6: Again, over a two hour period groups are confronted with the same problem that they had in Week 1. The difference is that new parameters are set on the day. For example in the beam project they may have a different span, load and deflection criteria to design to.

Lectures and tutorials were held each week. They had two purposes: to support the project work with relevant theory, and to cover basic theory that may not have been required for the projects but was considered foundational. A celebrated example of such theory is the 'free-body diagram'. Need for its use for the beam project was minimal but its understanding for more complex problems was considered mandatory.

Assessment was not to be the focus of the subject, and efforts were made to move away from a large emphasis on a final exam. Due to the need to assess knowledge of basic laws, two quizzes were included (20% each), but there was to be no final examination as such. Project assessment was not focused on results obtained ('getting the right answer'), but on the evidence students could provide of learning from participating in the activities. Project assessments consisted of reflective reports (10%) and design reports (5%), for each project.

Initial implementation (2005)

Once the decision was made to go ahead with this subject, there was insufficient time to get all the content developed in advance. A 'rapid prototyping and concurrent design' approach was adopted. The main immersive, experiential learning tasks were developed first, in advance of lecture and tutorial content. Materials were ordered and key practicals designed and scheduled.

The weekly lecture and tutorial content was then devised to support the experiential based learning tasks. As some of this occurred close to the delivery time, it was important to liaise with the ten tutors. Weekly coordination meetings were held with tutors to outline the following week's activity and reflect on the previous week. Experienced tutors contributed ideas and also helped to develop content. Videos and photographs were taken of the different practical sessions to compare approaches and develop the best practice.

The rapid prototyping and concurrent design approach to developing the subject ensured that ENGG101 was delivered without delay, however, it did lead to a number of less than perfect situations. The instant review and the ability to address problems "on the fly" meant that the 2005 content hung together and produced more successes than failures.

Initial student responses (2005)

One of the most important forms of feedback on a new subject is the students' experiences of learning. We evaluated ENGG101 at the end of autumn session 2005 using a survey designed by Ms Maureen Bell, and academic development lecturer at the University of Wollongong's Centre for Educational Design and Interactive Resources. The survey involved both rating and free text answer questions, and was administered to all students at the end of each iteration of ENGG101 (2005 and 2006). For the rating questions a four level rating scale was used (strongly agree, agree, disagree, strongly disagree). Free text questions asked students "What is the most important or interesting thing you have learnt in ENGG101" and "What remains … unclear?". All of the students in each of the iterations of ENGG101 completed the survey (n=210 for 2005; n=249 for 2006). Abbreviations of some of the quantitative rating questions that were posed are provided and discussed later in the paper, as part of Table 1.

Here, we report the qualitative findings from student responses in 2005 to the free text section of the survey. The 2005 student evaluation generated some mixed reviews. For example: the fact that the implementation was of the rapid prototyping kind was identified by students: "the idea of an introduction to engineering is a great one but it is obvious that this is the first year it has been run".

Given that we were attempting to contextualise theoretical learning and generate motivation to learn, student comments on these two areas were of particular interest in the 2005 survey.

Qualitative comments from the survey suggested that for many students, the intent of the course was realised:
"Practicals are fun. I like how it helps me see how engineering works in practice not just theory"
"It is useful in the transition from an average Joe state of mind to looking at problems in real life and thinking on an engineering level, breaking down the problem and solving it in smaller portions"
" For me as an Engineering Studies student (High School subject) most concepts were simply revision however using the concepts learnt in Engineering Studies to solve actual problems was new and rewarding"

The survey demonstrated that for some students, a connection between theory and context was still not apparent:
"The course was very broad and did not seem to lead anywhere".

The quantitative findings (Table 1) also supported the conclusion that our first attempt at providing a context for first year engineering students had been largely successful. The qualitative survey results for 2005 then became useful for the additional information they could provide on the subject and how it might be improved for 2006.

Interestingly, some students commented on the learning design and contributed suggestions. For example:

> "Maybe construct a project in which students get a role specific to their discipline"

There were pointers to what should be given more consideration:

"ENGG101 lectures could be more orientated to the physical applications of the course content."

"The lecture and tutorial material seems disjointed"

"Equations should be explained in more easier terms"

There seemed to be a theme throughout the qualitative comments in the 2005 survey that lectures were not perceived to be relevant to the subject, and that they had a lack of connection with the tutorials and the practical work. This seemed to indicate problems with the role of the lectures relative to the experiential learning approach attempted.

The 2005 survey provided evidence that some of our objectives in designing and implementing ENGG101 were broadly achieved and others were not. Understanding of the relevance of theory, and its connection with problems requiring its use was cited as a learning outcome that was realised. The perhaps naïve objective of breaking the assessment centred learning approach of students was not realised.

Just as the evidence generated by the evaluation survey contributed to our rethinking and redesign of ENG101 for the second round of its implementation (2006), we were also influenced in the redesign process by a particularly relevant theory from education which we tracked down late in 2005.

Theoretical support for ENGG101

Accepting the mixed results of our first attempt at teaching ENGG101, we searched for confirmation that our original design for the learning in this subject was valid, and for answers on how the various aspects of a subject that is centred on enquiry based learning should be constructed. What we were developing was a 'praxis' approach to teaching that drew on and merged insights from practice and theory (Fawcett et al., 2002). In this case, as cited previously, our first efforts at designing and implementing ENGG101 were largely based on our observations over many years of practical teaching of mechanics subjects, and we generated further practical experience in the teaching of ENGG101 during 2005. To complete a praxis loop, we needed to spend time understanding relevant educational theory. Such theory might influence and be influenced by our practical experiences.

A review of educational theory increased our consciousness that the learning approach we were trying to implement in ENGG101 had a body of research supporting it. Experiential learning through immersion (Cambourne, 1988) has the capacity to engage student and so improve participation. Figure 3 which is based on Cambourne's model of student engagement provides a close analogy for the approach we had adopted in ENGG101. Our aim had been to provide degree students with a context for engineering analysis early in their program. We discovered that Cambourne's model for engaging students was very close to what we had done in our first year of ENGG101. We had not designed the process with this diagram in mind, though we had deliberately constructed a scenario that we had hoped would deliver engagement, interest and context to the student. Following our review and the analysis of our subject in relation to Figure 3, we have been able to extract each component of the diagram and relate it to part of the subject and its delivery.

Immersion on day 1 let the students know that they had arrived at university. The problem that was set (the balsawood beam) was sufficiently familiar to the students so that they would not drown in the instant immersion.

Assessment criteria were clearly laid out so that students would not suffer negative consequences if they explored new ideas, even if those subsequently did not produce the solution. The marks were awarded for the quality of the reflection rather than the accuracy or performance of their balsawood structure. The assessment framework helped to clarify the expectations for both lecturers and students.

Following the initial demonstration of solutions that worked well and those that did not, students, through the group reflection reports, identified the engineering skills required to optimise the solution. With a little direction, they were encouraged to take responsibility to research the gaps in their knowledge.

When sufficient skills were mastered, the engineering design problem was revisited and the students used their knowledge to predict the performance of their designs. They were now in a position to alter their designs to improve the efficiency. By the time the second attempts were built and tested, the participants were recognising how they had moved from an experiential process to an analytical one. This was brought home in a final reflection report.

Feedback was given during the large lectures, immediately after the final testing of the structures. Video clips, photographs and the results from across all tutorials were rapidly assembled. It was felt that the instant feedback was a valuable feature and helped to maintain the impetus and enthusiasm from the practical session.

ENGG101 – Round Two (2006)

The outcome of our review of theory was greater confidence that our approach was directed at some of the outcomes we sought. We were not simply experimenting with the students. This realisation strengthened our resolve to get the structure and implementation right. Using Cambourne's framework as a guide, we were able to structure our approach more formally for the second year. We drew on our experiences of teaching ENGG101, the qualitative and quantitative results of the student survey and Cambourne's framework in rethinking and redesigning particular aspects of the course.

During the second year, more emphasis was given to reinforcing the context of the problem and related theories. This was done by more directly establishing a range of engineering problems that would subsequently require the application of the particular fundamental knowledge then presented. The nature of problem solving in the context of specific problems was introduced. The promotion of abstracting problems into general physical phenomena was advanced. For example the analogy between a fluid stream and the trajectory of a ball was uncovered. In addition there was a more concerted alignment of lectures with the projects, for example the lecture on fluid flow was moved to be immediately after the first attempt at the tank design problem.

During the second year of operation, we continued to use the rapid prototyping and concurrent design methodology as a means to deliver continued improvement and adaptation, and as it allowed us to be more immediately responsive to the way students in the 2006 cohort were responding to ENGG101. There was also a need to induct a number of new tutors into

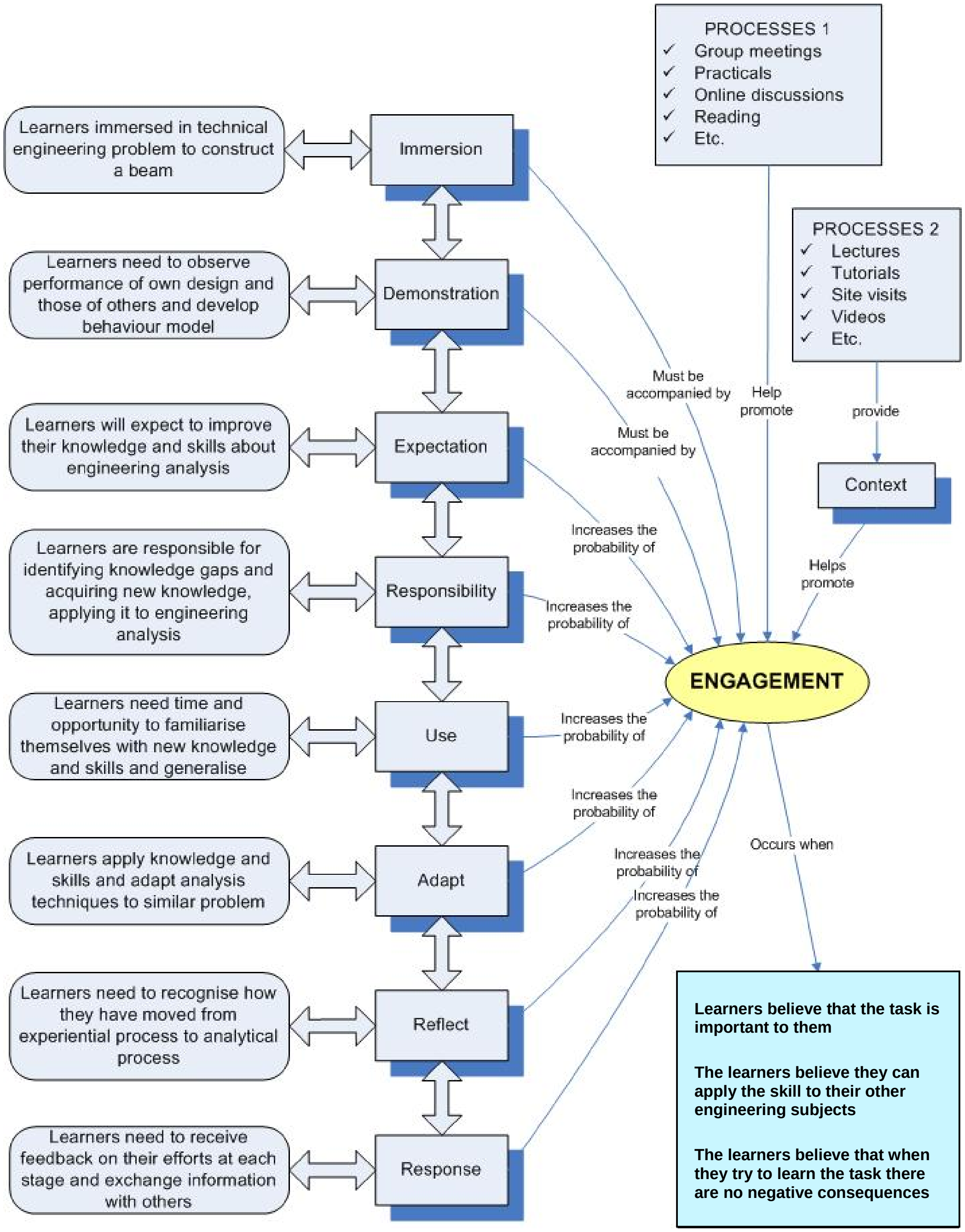

Figure 3: Rules of engagement for ENGG101 (based on Cambourne, 1988)

the approach as the class size increased significantly. The mix of experienced ENGG101 tutors and tutors new to the teaching approach helped to establish a belief in the subject and methodology.

Finally, a considerable number of administrative issues were addressed. The subject organisation was improved particularly in the light of the first experience. Although this was not a specific outcome of the review of theory, it was a result of our separation of issues eminating from the 2005 surveys related to organisation from the more fundamental learning design issues.

Student responses (2005 vs. 2006)

The statistics generated by surveying students' experiences of learning in ENGG101 during 2005 and 2006 indicated a significant improvement in the alignment between student perceptions of the subject and the learning objectives we had established. In terms of quantitative results, Table 1 compares the results for 2005 with 2006. It demonstrates a significant improvement in students' experiences of learning for the key learning areas we had identified when we first started designing ENGG101. For example: Question 1 "My participation in ENGG101 has caused me to understand how you can use science to solve engineering problems", and Question 6 "My participation in ENGG101 has caused me to see the relevance of science and mathematics to engineering" strike directly at the major reason for the introduction of ENGG101 and indicate both large improvements from 2005 to 2006 and now strong alignment between our objectives and what the students report.

The one counter to this is the result in Question 4: "Q4 My participation in ENGG101 has caused me to do more than just pass the course" which may counter the notion that students get fully engrossed in the subject and the learning. To address this it appears that some focus group questions are required to get to the meaning of this response.

Table 1 Comparison of overall results for iterations 1 and 2 (2005 and 2006)

	Survey Questions	Level of agreement			
Objective queried	**Questions posed: *ENGG101 participation...***	**2005**	**2006**	**Change**	**COMMENT**
Provide context for engineering analysis	Q1 ...caused me to understand how you can use science to solve engineering problems	79.7%	95.0%	15.3%	GREAT
Provide context for engineering analysis	Q2 ... caused me to identify whether I need additional knowledge to be able to practice as an engineer	84.0%	92.7%	8.7%	GOOD
Provide context for engineering analysis	Q6 ...caused me to see the relevance of science and mathematics to engineering	79.7%	95.0%	15.3%	GREAT
Provide context for engineering analysis	Q9 ... provided a real-life context for engineering analysis, mathematics & science	81.0%	91.0%	10.0%	GREAT
Engineering problem solving	Q5 My participation in ENGG101 has caused me to feel confident about tackling unfamiliar problems	48.3%	66.7%	18.4%	GOOD
Engineering problem solving	Q11 ENGG101 has helped me solve real-life engineering problems	66.2%	80.0%	13.8%	GREAT
Mastery skills development	Q7 ENGG101 Has sharpened my analytical skills	50.7%	80.5%	29.8%	GREAT
Mastery skills development	Q10 ENGG101 has helped me understand fundamental engineering principles	74.1%	90.5%	16.4%	GREAT
Learning approach	Q3 My participation in ENGG101 has caused me to feel motivated to understand the topics	53.5%	66.2%	12.7%	GOOD
Learning approach	Q4 My participation in ENGG101 has caused me to do more than just pass the course	53.5%	55.4%	1.9%	NEEDS ACTION
Learning approach	Q8 ENGG101 has stimulated my enthusiasm for further learning	42.4%	62.2%	19.8%	GOOD
Learning approach	Q15 I found myself working in this subject just to complete the assessment tasks	74.3%	68.0%	-6.3%	IMPROVEMENT
Learning approach	Q16 I found myself working in this subject in order to understand the topics	62.5%	64.3%	1.8%	NO CHANGE

From our survey of the second cohort of ENGG101 in 2006, qualitative comments obtained against the free text question “What is the most important or interesting thing you have learnt in ENGG101” reinforced the quantitative results and were supportive of the teaching techniques used. For example:

“ Solve real-world problems such as the tank and beam design and using formulas and theories to predict outcomes was excellent”

“ The simple nature of mathematical modelling formulae which can be applied to a variety of situations”

Conclusion

ENGG101 has proven to be a learning experience for all involved. Our rapid prototyping and concurrent design approach, combined with close attention to students’ comments on their experiences of learning and some educational theory have led to an iterative approach to improving this non-traditional approach to teaching engineering. The work is still underway. Some theory suggested that some aspects of what we were trying to achieve might be unrealistic and that our focus needed to change. Specifically, the ‘assessment-centred’ approach of students is a natural reaction to the University system of education as it is currently structured. Rather than criticising students for this, an approach known as ‘constructive alignment’ (Biggs, 2003) may be a way forward. We have begun to change the approach to assessment to achieve constructive alignment between assessment and the learning objectives. The assessment tasks are now more clearly focused on the learning objectives, and some extrinsic rewards have been introduced (eg. an award to the group with the best overall performance as reflected in their project report).

The main lesson from our experiences of designing and redesigning ENGG101 was that theory gave us confidence in our ideas and a reason to continue to work on its implementation. By attempting a solution, measuring the results and then searching for guidance through theory, we were able to better align our teaching to our objectives. The results so far are encouraging. We plan to continue to implement changes as a result of the latest iteration, more evaluation and delving into other educational theories. In summary we can say that praxis works.

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