Go and see and touch and feel –
An introductory case study for Civil Engineering students

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Abstract

Civil engineering students often have difficulties visualising abstract theoretical concepts in early stages of their education in structures. Over the last few years we have developed a structural experience for our students that helps to make these abstract concepts concrete. Embedded in this experience are strategies that reflect both 'good teaching' practice and relevant management strategies. We have developed a case study with accompanying worksheets that become the scenario for rich assessment tasks for later university theoretical work. Australian Technology Park (ATP) is an excellent site for such an experience because the 'new' structure has been built inside the 1800s structure and both are visible. The number and variety of structural elements and materials used at the ATP is unparalleled in a site so accessible to our students. The strategies students learn during this experience also provide transferable learning to use on other structures they encounter generating deeper, life-long learning. Student feedback has indicated that this experience is worthwhile. The development of this experience has led to the documentation of the case study to the point where it has now become a self-guided tour booklet that can be used by school teachers and their students in relevant subject areas as well as members of the public interested in engineering history at the ATP. This paper details the experience with reference to the underpinning educational theories.

Keywords:

case study, learning styles, civil engineering, mechanics, statics, materials, Genchi Genbutsa, Australian Technology Park.

Teaching and learning issues for beginning civil engineering students

The study of engineering mechanics

> "…requires more than a mere knowledge of the physical and mathematical principles of mechanics; also required is the ability to visualise physical configurations in terms of real materials, actual constraints, and the practical limitations which govern the behaviour of machines and structures. One of the primary objectives in a mechanics course is to help the student develop this ability to visualise…" (Meriam & Kraige, 2003, pg vi).

The study of mechanics aims to equip students with the skills to explain and predict the response of bodies to the action of forces, as such it is seen as a "…key enabling discipline that underpins progress across a diverse range of industry sectors" (National Committee of Applied Mechanics, 2004, pg 1) and is so important that "No other subject plays a greater role in engineering analysis than mechanics" (Meriam & Kraige, 2003, pg 3).

“We can no longer assume all students will achieve by being taught the same way, and consequently new teaching practices are required.” Houghton (2004 pg 1), in his recent publication goes on to summarise the development of the theories of Learning Styles and the importance of recognising your own learning style and those of your students then “to adopt approaches to teaching that enable students who have different learning styles to learn effectively.” Research in learning theory has developed the four dimensional learning continuum discussed by Houghton to eight and possibly more Multiple Intelligences described by Armstrong (2000).

Many civil engineering students are visual/spatial learners and often have difficulties with concepts that are presented in an abstract theoretical text-based or lecture format in early stages of their education in structures. A free body diagram is seen as an abstract group of lines on a page until they can see how it can be applied to a real structure. Even photos do not give a 3D, scale or tactile experience. Many junior students have no idea of the names of civil engineering structural elements, typical sizes, commonly used construction materials or joining methods when they enter our course. The study of Statics can become, for them, an exercise in looking at lines on a page and applying formulae and language without really understanding why they are appropriate.

In light of the research into learning styles we have had to look anew at the push towards ‘high-tech’ virtual teaching strategies and recognise the value of using more traditional ‘low-tech’ strategies where they are appropriate.

Our current aim in teaching Statics is to help students develop an understanding of structures, as opposed to ‘rote learning’ of theorems or mathematical problem-solving strategies; to move them from being child-like, teacher-directed learners to adult learners where they are learning because they want to, and see a relevance to their chosen careers and the world around them. This gives them a real-world underpinning for their learning and allows them to take ownership of mechanics concepts and learning processes. We aim to provide transferable learning to use on other structures they encounter later, generating deeper, life-long learning (Armstrong 2000) about structures.

The Institution of Engineers, Australia sees this capacity for life-long learning as an essential objective of current engineering education:

> “…the depth of knowledge and understanding…that are fundamental to real engineering capability, come from equipping students to learn for themselves… Programs should…develop the capacity and motivation for the lifelong learning that will be essential whatever the content of the first degree” (Institution of Engineers Australia, 1999, pg 5).

The Japanese management strategies for engineers “Genchi Genbutsu” has the English translation “Go and see for yourself to thoroughly understand the situation” (Liker, 2004, pg 223). We have translated this as ‘Go and see and touch and feel’. This strategy has been expressed in a variety of ways throughout history and various cultures, for example many of us have heard the saying “I hear and I forget. I see and I remember. I do and I understand.” By incorporating this philosophy into our teaching we are able to build on our students’ existing knowledge and extend it.

The case study

We have used the teaching and management strategies discussed above to create an integrated case study that gives our Statics students an experience of the real world to use as they visualise the theory presented in later parts of the course, making abstract concepts more concrete. Embedded in this experience are strategies that reflect both ‘good teaching’ practice and relevant management strategies. We have also developed accompanying worksheets and rich assessment tasks for later university theoretical work. This traditional hands-on teaching strategy gives students a common language or memory bank to use when talking about specific structural elements so that they can articulate their understanding (or lack of understanding) of structures in correct technical language. We have chosen Australian Technology Park (ATP) as the site for this experience. ATP is an excellent site for such an experience because the ‘new’ structure has been built inside an 1800s structure. Both are visible, and the number and variety of structural elements and materials used is unparalleled in a site so accessible to our students. (Figures 1 and 2)

Figure 1. The workshop display showing the original structure and some machinery.

Figure 2. Looking down into the Atrium showing the new structure within the original structure.

The ATP is an incubator for businesses involved in leading edge technology, as well as providing offices for some units from institutions of higher education. It is situated in refurbished locomotive workshops at Redfern in Sydney. Elements of the original structure were shipped to Sydney from Britain in the late 1800s, along with most of the machines used to build the locomotives. The original structure was retained when a major refurbishment took place to create space for offices, exhibitions and conference facilities.

One of the major advantages of the ATP site is that a comparison of ‘old’ and ‘new’ materials, structural forms, and construction methods can be made during the visit. For example, some of the old structural elements are of cast iron and the new elements are hot-rolled sections; and old rivetted structures can be compared to new bolted elements. ATP provides a ‘back to the future’ style experience of structures, a structural ‘family tree’ or ‘reality TV’ experience. Understanding both the old and new types of structures is still relevant to today’s civil engineers as both exist in our world and still need to be maintained by new generation engineers.

Our case study is timed so that students have just covered the basic classification of structural supports. It contextualises this learning by giving students the opportunity to see and in some cases touch these different types of supports, as well as other basic structural elements like beams and columns. Some of the structural elements or supports discussed on the visit include:

- curved beams used in conjunction with various machinery
- supports and the load path for a small crane structure
- cast iron columns and their supports
- hot-rolled steel universal beam sections and their connections
- steel and timber elements of the new stairway – highlighting use of inclined beams
- roof trusses constructed of elements of various cross-section
- connections modelled as pins
- bracing
- crane girders with three different shapes.

The first element discussed on site is outside the locomotive workshop building and consists of the pulley system used to tension the overhead wires for electric trains. A sheet of butcher’s paper is pegged to the fence in front of the pulley system. Students are asked to draw the free body diagram of one of the pulleys based on work covered in lectures on the statics of particles in two dimensions. Once students have constructed this free body diagram for a particle in two dimensions they can see what forces will affect its equilibrium and write the two equations of equilibrium that apply to the pulley. This process can take some time as it is often the first time the students have actually tried to apply a theory from Statics lectures to a real structure, and it can take time for these links to form in the students’ mind. It is important not to rush them at this point. At last, a free body diagram becomes more than just an abstract group of lines on a page. They can now see how it can be applied to a real structure. It is only when they can apply the theory to a real structure that they have really learnt what the theory is all about. However, when they do make the links they also enjoy the buzz of knowing “I can do this”. Having been guided through the process of applying basic concepts of mechanics to one real structural element which can be modelled as a particle, it becomes easier for students to consider constructing free body diagrams and applying equilibrium to the rigid bodies and structural elements inside the workshop (see Figure 3). This parallels the order in which material is covered in the subject syllabus i.e. the equilibrium of particles is covered before the equilibrium of rigid bodies.

The crane girders at ATP are interesting as they allow illustration of the idea that there is usually more than one way to solve a structural problem. This introduces the students to the world of engineering design where, unlike many high school problems, there may be more than one 'right' answer. While the three girders investigated during the case study do essentially the same thing, they differ in form:

- welded plate
- rivetted plate
- equal angle truss.

A comparison is then made between the roof truss viewed earlier and the equal angle truss used as the crane girder. One of the issues discussed is: why can the equal angle truss connections be modelled as pins, even though they don't look like the obvious pin joints of the roof truss? Two of these crane girders have a bottom flange that is curved in profile and the other has a trapezoidal profile. One of the key questions here is: why would the designers have shaped the bottom flange? Later in the semester, after bending moment diagrams have been covered, the students are asked to consider this problem again, and can now develop an answer by completing the earlier worksheets, building up layers of bending moment diagrams as an introductory treatment of influence lines. The students can then answer the question of what the designers were trying to achieve by shaping the bottom flanges, and this leads neatly into proposing what shape these girders might be if they were constructed today.

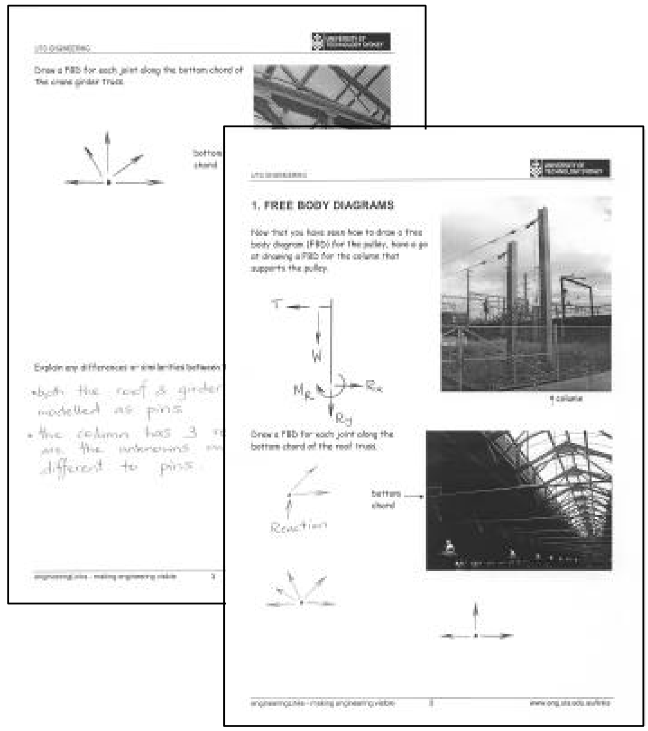

Figure 3. A sample worksheet for the case study.

Assessment

The site visit provides the students with an opportunity to apply concepts in mechanics with staff on hand to answer questions, or prompt them.

Worksheets have been developed that are completed both during and after the visit to reinforce simple concepts and language. A post case study project (Special Project – see Figure 4) asks students to go out and find their own structure and report on similar elements to those seen at ATP.

The Special Project forces them to demonstrate that they can apply these principles without this 'safety net'. Because the students are 'L-plate' engineers the bulk of the marks are allocated for showing that they have gone through the process and for how well they justify their conclusions.

A final assessment of the concepts learned from the case study is via related exam questions in their final exam for the subject. These quiz or exam questions have also been based on a structure or element observed on the site visit, digital photography making this process relatively simple. Thus the site visit is not just a 'one off' fun activity, but is integrated into the whole semester's teaching.

Special Project

Go and See and Touch and Feel again!
Due Week 12
5% of total assignment mark

Find a structure and report on similar elements to those seen at ATP - supports, connection, or some other detail.

Take a photo or draw your chosen structural element.

Draw a FBD for your element – as much as you can, obviously you will not know the magnitude of loads or reactions, but you can show where they might act.

Describe your chosen structural element including the following:

- The nature & location of the overall structure
- What it is you have chosen i.e. is it a support, a connection …?
- The materials used
- Your guess/estimate of the age of the structure
- Your guess as to how the element should be modelled i.e. pin, roller etc. Justify your guess
- Any other interesting information

The description should be no more than one A4 page.

Figure 4: The follow-up Special Project assessment task.

Results

The case study shows the students that the material covered in this early stage subject is applicable to 'real' structures, and that they can actually 'do Statics' themselves. The enjoyment of knowing "I can do this" creates positive reinforcement that encourages students to apply their Statics knowledge to more complex structures. They begin to recognise the importance and relevance of this subject to them as potential civil engineers rather than as simply students moving through an academic course of study.

Review of the students' assessment tasks shows that most of them understand the links between classroom and real-world examples. Several students have had trouble confining themselves to one structure for their Special Project as they get structures 'under their skin'. Students also come into lectures and feel the need to tell me that "…I saw this great space truss the other day..." or send photos of interesting structures even after they have completed the subject.

From student feedback it has been realised that one other advantage of the case study is that students meet other members of the mechanics and structures teaching staff. Several other staff members kindly attend the case study. This provides students with an opportunity to ask questions more privately if they feel too intimidated to ask in front of the whole group. Students also develop stronger relationships between each other and staff based on this shared 'off-campus' experience. Accompanying staff members are very supportive of the experience.

One lecturer who also teaches a subsequent subject Structural Analysis says that

"… Statics is one of the most important subjects taught in engineering because it underpins the entire structural engineering strand by laying the foundation for learning how to idealise, analyse and design load-bearing structures … [This] innovative approach … has made a positive impact on students' appreciation of the subject … I remember a student asking me immediately about the validity of idealising member connections in trusses as a pin. We were then able to briefly discuss assumptions made in structural analysis and the level of accuracy of computations." (A. Selah 2004, pers. com.)

Student feedback surveys have indicated that this experience is worthwhile. When asked "What did you particularly like in this subject?" replies were received like:

- "I particularly liked the fact that you could relate the problems to real life scenarios…"
- "That it's 'real' engineering, it teaches you how to look at structures so that you can design them…"
- "Lecturer made things clear and easy to understand…"
- "The excursion and special assignment…"

One particular student, when discussing her subsequent internship, relates that

"The trip to the Australian Technology Park was more than just an excursion … What was most beneficial about this project was that we were able to broaden our own analytical skills by predicting where the loading forces might be found within our chosen structure. The skills that I have learned to adapt from this project are still useful for me everyday while doing my work experience out on site." (C. Mikhail 2004, pers. com.)

Outreach opportunities – a bonus

The development of this experience has led to a bonus opportunity. After enquiring about the availability of a guided tour for the public of the engineering structures at ATP we found this lacking. Therefore we decided to document our case study to the point where it has now become a self-guided tour booklet that can be used by school teachers and their students in relevant subject areas as well as members of the public interested in engineering history at the ATP.

The materials developed together with teaching resources of worksheets and background information are included as part of the UTS Engineering Outreach program and can be purchased from the authors. The aim of this 'Engineering Links' program is to make engineering visible which this case study does well. Outreach staff are also available to run the case study as a guided tour of ATP with school students when introducing them to engineering as a field of study and career option. Sample pages from these resources can be seen in Figure 5.

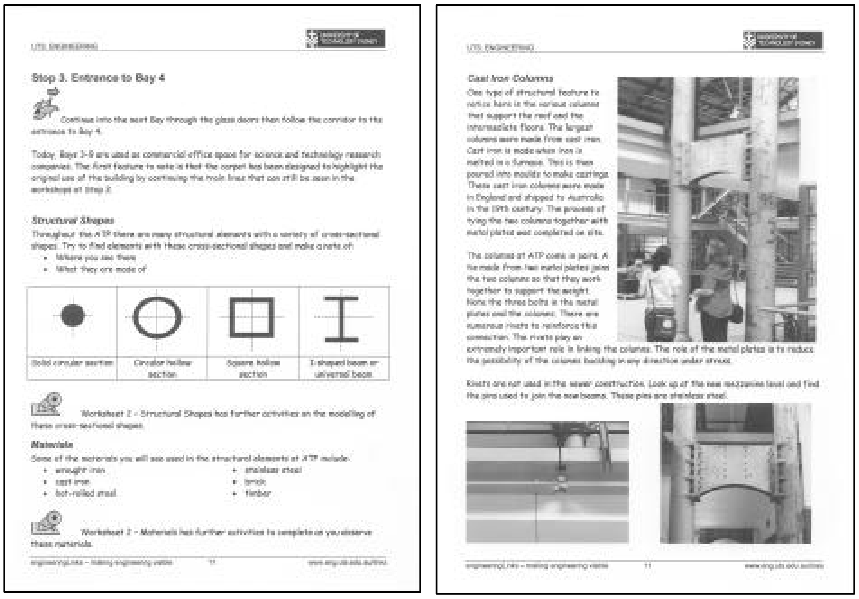

Figure 5. Sample pages from the Self Guided tour resources for Australian Technology Park.

Conclusions

"I hear and I forget. I see and I remember. I do and I understand". While virtual reality can be an effective substitute for reality, it is just that – a substitute. At UTS we are lucky that we have access to the 'real thing' in our own backyard. The common frame of reference provided by this case study means meaningful links can be created from this foundation to new material in the Statics syllabus. The benefits of the case study to both the students and staff mean that it is now an integral component of the teaching in this subject. The bonus is that the audience for the materials we have developed has now grown and is useful at a number of different levels. Our recommendation for all Statics classes is to "Go and See and Touch and Feel".

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