BRIDGE BUILDING USING TEAMWORK

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ABSTRACT

This paper presents the results from a problem-based learning module at the University of Limerick. The module, 'Design Studio' is 100% continually assessed, 85% of which is allocated to team-based assignments, the remaining 15% is for a peer assessed report and presentation on a famous engineer, building or engineering failure. The assignment discussed in this paper comprises 60% of the module marks and involves the analysis, design, construction and testing of model truss bridges (Figure 1). This problem-based learning approach is introduced in the first year of the construction management & engineering programme. The Bridge building exercise presents an element of realism in the students' project work that yields amongst other things, peer assessment skills and tangible management experience for their cooperative work placement in year 3. The module structure and format has resulted in students engaging enthusiastically with the project and delivering work of a high calibre. While the logistics of conducting such assignments place heavy demands on scheduling resources and support staff, experience at the University of Limerick has shown that the learning outcomes delivered are well worth the effort.

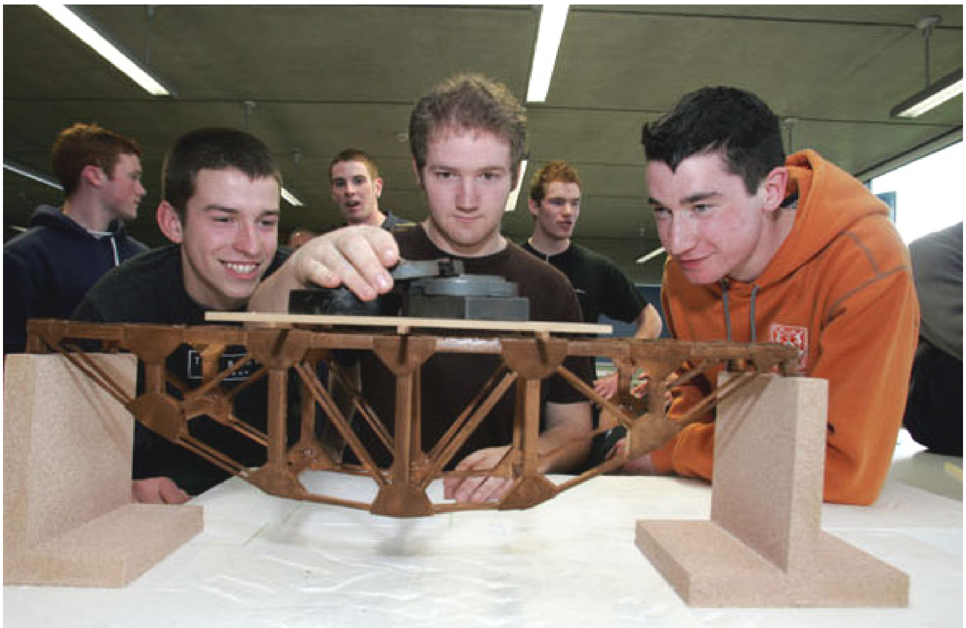


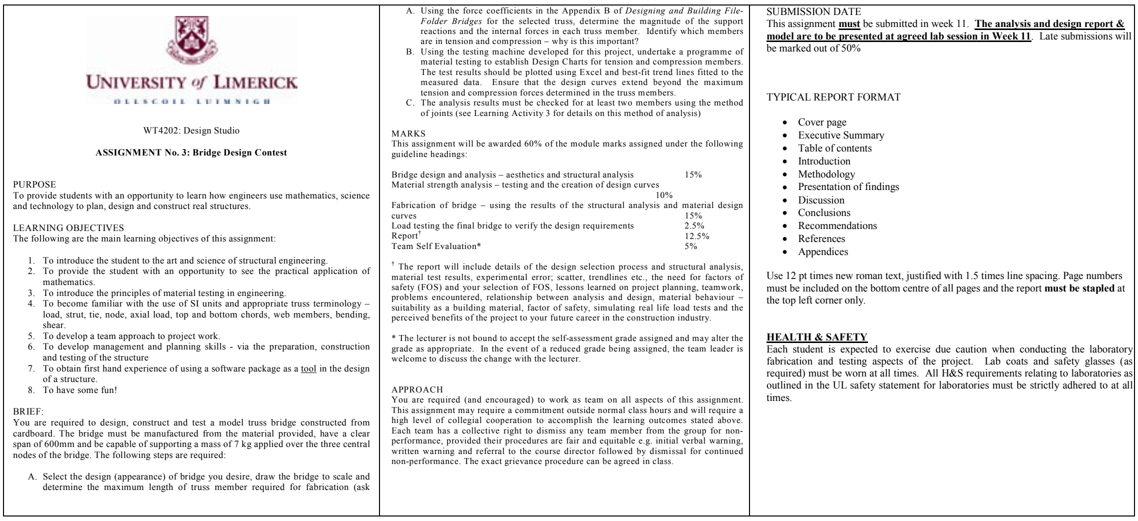
Figure 1: Testing of Model Bridge

INTRODUCTION

The bridge building project is the brainchild of Prof. Stephen J. Ressler [1] of the United States Military Academy, West Point, New York. Ressler's work provides an excellent introduction to engineering mechanics without necessarily having to become immersed in the analytical rigour associated with this topic. A well-illustrated technical manual and an interactive bridge design programme allow the students to 'dip in' and develop the necessary expertise to solve design and construction problems as they are encountered in the project.

METHODOLOGY AND RESOURCES

Typically, eighty students are introduced to the project through the university's virtual learning system. A detailed project brief (Figure 2), associated documentation and web links are posted on the module's dedicated page [2]. The group is divided into four studio groups of 20 and further subdivided into five teams of four. Each team then selects a team leader to manage the project. A 2-hour laboratory slot per week for six weeks is allocated to each studio group in addition to a fabricating toolkit and access to specially constructed material testing machines (Figure 3).



UNIVERSITY of LIMERICK
OLLSCOIL LUIMNIGH

WT4202: Design Studio

ASSIGNMENT No. 3: Bridge Design Contest

PURPOSE
To provide students with an opportunity to learn how engineers use mathematics, science and technology to plan, design and construct real structures.

LEARNING OBJECTIVES
The following are the main learning objectives of this assignment:

1. To introduce the student to the art and science of structural engineering.
2. To provide the student with an opportunity to see the practical application of mathematics.
3. To introduce the principles of material testing in engineering.
4. To become familiar with the use of SI units and appropriate truss terminology – load, strut, tie, node, axial load, top and bottom chords, web members, bending, shear.
5. To develop a team approach to project work.
6. To develop management and planning skills - via the preparation, construction and testing of the structure
7. To obtain first hand experience of using a software package as a tool in the design of a structure.
8. To have some fun!

BRIEF:
You are required to design, construct and test a model truss bridge constructed from cardboard. The bridge must be manufactured from the material provided, have a clear span of 600mm and be capable of supporting a mass of 7 kg applied over the three central nodes of the bridge. The following steps are required:

A. Select the design (appearance) of bridge you desire, draw the bridge to scale and determine the maximum length of truss member required for fabrication (ask

A. Using the force coefficients in the Appendix B of *Designing and Building File-Folder Bridges* for the selected truss, determine the magnitude of the support reactions and the internal forces in each truss member. Identify which members are in tension and compression – why is this important?
B. Using the testing machine developed for this project, undertake a programme of material testing to establish Design Charts for tension and compression members. The test results should be plotted using Excel and best-fit trend lines fitted to the measured data. Ensure that the design curves extend beyond the maximum tension and compression forces determined in the truss members.
C. The analysis results must be checked for at least two members using the method of joints (see Learning Activity 3 for details on this method of analysis)

MARKS
This assignment will be awarded 60% of the module marks assigned under the following guideline headings:

Bridge design and analysis – aesthetics and structural analysis	15%
Material strength analysis – testing and the creation of design curves	10%
Fabrication of bridge – using the results of the structural analysis and material design curves	15%
Load testing the final bridge to verify the design requirements	2.5%
Report†	12.5%
Team Self Evaluation*	5%

† The report will include details of the design selection process and structural analysis, material test results, experimental error; scatter, trendlines etc., the need for factors of safety (FOS) and your selection of FOS, lessons learned on project planning, teamwork, problems encountered, relationship between analysis and design, material behaviour – suitability as a building material, factor of safety, simulating real life load tests and the perceived benefits of the project to your future career in the construction industry.

* The lecturer is not bound to accept the self-assessment grade assigned and may alter the grade as appropriate. In the event of a reduced grade being assigned, the team leader is welcome to discuss the change with the lecturer.

APPROACH
You are required (and encouraged) to work as team on all aspects of this assignment. This assignment may require a commitment outside normal class hours and will require a high level of collegial cooperation to accomplish the learning outcomes stated above. Each team has a collective right to dismiss any team member from the group for non-performance, provided their procedures are fair and equitable e.g. initial verbal warning, written warning and referral to the course director followed by dismissal for continued non-performance. The exact grievance procedure can be agreed in class.

SUBMISSION DATE
This assignment **must** be submitted in week 11. **The analysis and design report & model are to be presented at agreed lab session in Week 11**. Late submissions will be marked out of 50%

TYPICAL REPORT FORMAT

- Cover page
- Executive Summary
- Table of contents
- Introduction
- Methodology
- Presentation of findings
- Discussion
- Conclusions
- Recommendations
- References
- Appendices

Use 12 pt times new roman text, justified with 1.5 times line spacing. Page numbers must be included on the bottom centre of all pages and the report **must be stapled** at the top left corner only.

HEALTH & SAFETY
Each student is expected to exercise due caution when conducting the laboratory fabrication and testing aspects of the project. Lab coats and safety glasses (as required) must be worn at all times. All H&S requirements relating to laboratories as outlined in the UL safety statement for laboratories must be strictly adhered to at all times.

Figure 2: Project Brief

The students are required to design a paper bridge to span 600mm and support a mass of 7kg placed uniformly over its central section, transverse beams deliver the load to the truss joints as point loads (Figure 1). The mass is converted into units of force (W) and the proportion of W distributed to each individual truss member determined using coefficients taken from a database of pre-analysed truss bridges (Figure 4). Once the form of the bridge and the design forces are determined, the design and construction of the structure commences. As the design is progressed the group intuitively learn about the concepts of equilibrium, tension & compression (assigned + and – symbols respectively beside the coefficients in Figure 4), stability, ductility and brittleness.

In week 3 of the project a short tutorial is provided to demonstrate the method of analysis used to determine the force coefficients. This instruction is timed to coincide with the student's 'inquisitiveness' as to the origins of the coefficients and is receptive to developing the analytical skills necessary to calculate the coefficients, particularly when the theory can be applied as part of the project. The tutorial introduces the equations of equilibrium; and applies these to determine the support reactions and forces in the truss members at the support (see Joint A in Figure 4).

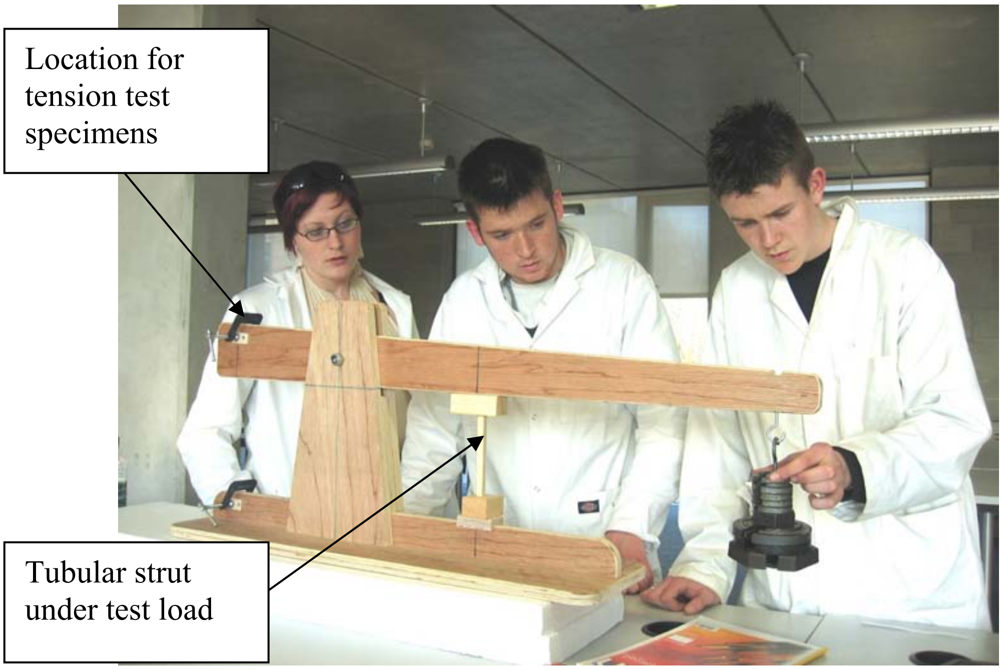


Figure 3: Compression testing of fabricated tube section using the material testing machine.

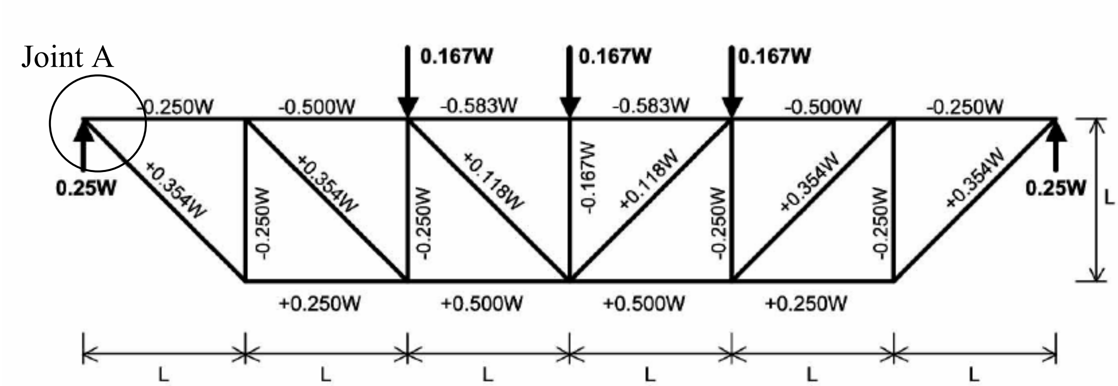
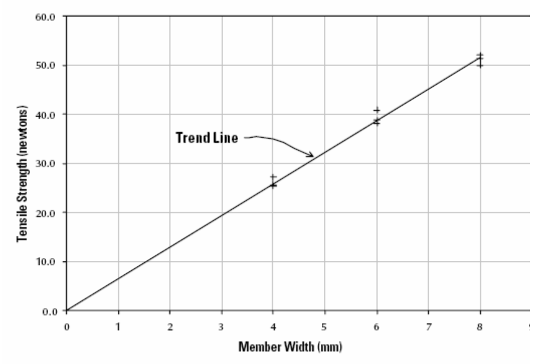
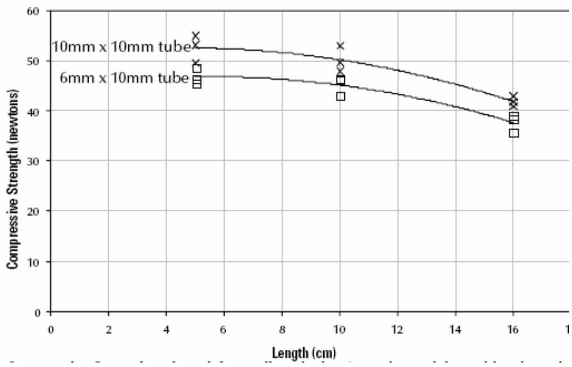


Figure 4: Force coefficients for Pratt deck truss (Span = 6L, Height = L)

The testing machine shown in Figure 3 utilises the 'law of the lever' to determine the tensile and compressive strength of the selected prototype members. Taking the tensile tests as an example, a series of equal width strips are cut from the paper sheets. Three specimens are tested for each size selected. The tensile mass supported at failure is recorded in each case, converted into units of force and corrected for the mechanical advantage of the lever. The same procedure is adopted for other size strips and the results plotted on an Excel chart (Figure 5a). This allows the students to become familiar with the use of spreadsheets, plotting trend lines (as an aid to design) and most importantly observe the scatter in strength results when 'real' materials are tested. The students also (inadvertently) discover material anisotropy when they find that different material strengths are obtained depending on the orientation of the paper fibres when tested. A similar approach is taken in the development of design curves for compression members but with the member length rather than its width being the dependent variable (see Figure 5b). As compression tests are conducted the students learn how slender members buckle under compression and how to modify their designs to create struts capable of supporting the design loads.



(a) Tension Test



(b) Compression Test

Figure 5: Typical tension and compression test results showing the scatter in test data.

With the material tests complete, design curves similar to those in Figure 5 are used to select truss member sizes that will safely and economically support the design load. The concept of a ‘factor of safety’ and its importance in structural design is discussed at this point. A scale drawing of the bridge design is then used as a template for fabricating the bridge (Figure 6). The finished structures are then weighed and tested up to the design load. Following a successful test, a winning bridge is chosen based on economy of material (minimum weight) and aesthetic appeal. The successful team receive a prize sponsored by a consulting structural engineering firm in Limerick who, along with the author, select the winning structure.

It can be argued that the real learning takes place following the judging contest; intrepid teams decide to put their creations to the ultimate test by loading the bridges to failure. Two types of failure normally ensue; firstly, collapse due to lack of three-dimensional (3-D) stability and secondly collapse due to failure of individual truss members. The absence of lateral bracing and the resulting lack of 3-D structural stability often expose the uninitiated as they watch their bridges twist, shift laterally and shed their load; often before the design value is applied – a valuable lesson for those hoping to avoid a visit to court during their career in construction! The more astute teams recognise the necessity for the seemingly innocuous bracing members (and the stability they provide) as their bridges continue to receive load until collapse occurs with the buckling of a strut or fracturing of a tension member. The entire event is recorded by video so that additional learning is gained when the class observe the various collapse modes and the exact failure trigger when the recording is played back in slow motion. Finally, each team prepares an engineering report that includes facts and commentary on methodology, test results, calculations, drawings and photographs along with a peer assessment of the team’s performance. The report is also fully referenced using the Harvard method.

Figure 6: Bridge fabrication using a scale drawing as the template.

RESULTS

The author's opinions on the bridge building exercise are summarised as follows:

1. The holistic approach of the project leads to the simultaneous development of skills in project management, graphics, structural analysis & design, information technology and report writing. The bridge building exercise provides an excellent means to unify these skills and prepares the students for engineering practice in the 'real world.'
2. Increased enthusiasm for the programme and the realisation that the course is meeting their expectations – an experience not always prevalent in the first year of engineering programmes.
3. The project provides students with firsthand experience of the relationship between materials testing and structural design. It also illustrates the non-uniqueness of material properties and provides tangible evidence of the importance of a factor of safety in engineering practice.
4. With regard to the learning experience, the problem-based approach tends to let the individual skills of the team members come to the fore by permitting each student to operate in their preferred learning style. Therefore, the individual with leadership, dexterity, graphics or communication skills can combine their skills with those of other team member's to produce work of a high calibre while having FUN in the process!

DISCUSSION

The paper has demonstrated many of the benefits to be gained by introducing problem-based learning in the first year of an undergraduate engineering programme. Student feedback at the end of the module is unanimously positive with requests that other modules adopt the same format.

From the educator's viewpoint, the relaxed and fun format of Design Studio provides an environment where the students are actively learning throughout the module. It is also observed that students are more willing to engage with the lecturer in the small group format and to seek clarification on technical challenges in the project. Moreover, the individual talents of the team members be they managerial, analytical, creative, or model building skills combine to create both enthusiasm and class spirit which ultimately leads to project work of a very high standard. The students responded favourably to being empowered to peer assess their performance but consistency in this proved difficult to monitor from the lecturer's viewpoint. The problem-based approach contrasts dramatically with the traditional lecture format where communication is essentially one-way and learning primarily assessed by end of semester examination – this often comes too late for some students who are uncomfortable seeking clarification in large lecture halls for fear of drawing attention to themselves.

In addition to the obvious engineering skills developed during the project, the students gained valuable experience in time management; lack of leadership in the early stages of the project (as the students grappled with this new and unfamiliar territory) required additional work outside the scheduled laboratories so that the project could be completed on time; in fact, it took until week three for the students to become comfortable with the active learning approach and to start making visible progress on the bridge challenge.

The university is also to be commended for their support of core teaching activity, the logistics of facilitating such modules place heavy demands on scheduling resources and support staff, however the benefits to students have proven to be well worth the effort.

In closing, problem based learning is an excellent means of instruction that will both excite and create enthusiasm on an engineering programme. I wholeheartedly endorse the following Chinese proverb:

"I hear and I forget
I see and I remember
I do and I understand"

REFERENCES

1. Ressler, S. J., Designing and Building File-Folder Bridges – A Problem-based Instruction to Engineering, US Government Publications, 2001.
2. Phillips, D. T., Design Studio Notes, University of Limerick, 2006.