The use of model making (and breaking) in freshman Engineering Statics courses.

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Abstract

In the Engineering degree programs that traditionally commence with an introductory statics course, instructors typically search for examples and applications that can explain and bring to life the physics and mathematics involved. Laboratory classes designed to reinforce theory via experiments are the norm but are often limited by available time, suitable equipment and other resources. Such classes may be 'tolerable' experiences for students rather than eagerly sought after learning opportunities.

Since 2000, the author has used competitive making (and breaking) of structural models in a first year Engineering statics course for Engineering students at Victoria University as an alternative to traditional laboratory experiments. Models are made from simple low cost materials and are easily assembled. The enthusiasm with which students approach these model making/testing/breaking assignments has convinced the author of their worth and is further reflected by improved grades, reduced drop-out rates and a strongly enhanced level of positive student motivation.

Models must be made within tight specifications and are accompanied by a comprehensive documented report. Competitive testing (i.e.'breaking') of models takes place during an end of course session. Model assessment is based on structural efficiency achieved, measured as the ratio of breaking load to model mass. During a testing in front of the assembled class, the instructor has a unique opportunity to utilise the many and varied failure modes exhibited by models, as a 'real time' teaching and learning experience. Relevant linkages can also be made to future courses such as material science, structural analysis, structural design and serviceability. In one semester, high efficiency models are identified and students are offered an opportunity to further improve their models for an annual model making/breaking competition offered to freshman Engineering students from across Australia. In 2001 and 2002, Victoria University students as taught by the author won this competition.

1. Introduction

The author's underlying philosophy of Engineering education has been formed over many years and is "experience and practice" (wherever possible) within the teaching program after all the key distinguishing characteristic of professional Engineers is the successful design of practical solutions to real problems. In 2001 the author replaced all laboratory experiments within the two semester freshman Statics course "Solid Mechanics A", with a program of competitive model making and breaking. The course applies to students from Architectural, Building, Civil, Mechanical and Robotic Engineering,

The rationale for this change stemmed essentially from Dewey (1) who proposed that
"If an experience arouses curiosity, strengthens initiative".....(it).... "sets up desires and purposes that are sufficiently intense to carry a person over the dead places, in the future".

In other words such experiences can motivate an individual to go on and succeed when things get difficult. It is the author's aim through model making (and breaking) to create experiences that will deliver this sort of benefit to students as early as possible, and motivate them to finally succeed in their chosen Engineering degree.

Dewey also stated,
"A primary responsibility of educators is that ………..they recognize…….what surroundings are conducive to having experiences that lead to growth. Above all, they should know how to utilize the surroundings, physical and social, that exist so as to extract from them all they have to contribute to building up experiences that are worthwhile."
This is the reason that the making (and breaking) of models is set in a competitive environment where (within specifications) any/all designs are possible and all are assessed against the simple criteria of structural efficiency, at the point of failure under load.

Grinder (2), in his work on the application of Neuro Linguistic Programming (albeit in primary and secondary education) proposed that educational experiences delivering information to the brain through as many of the five senses as possible are inherently 'better' experiences and have longer lasting and deeper 'impacts' upon the receiver. Students (therefore) make their models at home (with all that this entails) for the benefits that the experience delivers to them during (and after) the design/fabrication process. (Their enthusiasm for the design/fabrication process alone has proved almost sufficient reward in itself).

Claxton, & Murrell (3), in reviewing learning styles discuss the well known theory of "experiential learning" and recommended a four step process in which an immediate and concrete experience is followed by a reflective observation on the experience which (if successful) should lead one to abstract conceptualizations whereby generalizations and principles are developed into theories for future use. These theories can lead to active experimentation, testing what has been learned and thus closing a learning cycle.
Felder (4 & 5) also identified the different learning styles of students and recommended techniques that included problem-oriented teaching, co-operative learning, a balance of real and relevant (concrete) and abstract (theoretical) information as the most effective teaching techniques.

During the model making activities in "Solid Mechanics A" there are many opportunities for concrete experiences for example in materials testing or the prototype examination of alternative model configurations. When the testing (ie. "breaking") of completed models takes place, the potential quantity and quality of learning experiences is significant. By the end of a testing session the range of model configurations and the many alternate ways/loads by/at which they fail, could not be easily created in any other meaningful way.

Impromptu discussions are called for by the instructor/tester on issues such as material properties, model failure modes and pointers to the more advanced strength design/serviceability concepts that will follow later in each student's course.

2. Teaching program and incorporated models

"Solid Mechanics A" is a two-semester freshman course common to all five engineering degree programs offered within the school. Students also take two semester subjects in each of Physics and Mathematics as co-requisite courses. Each semester subject earns 10 credit points from a total of 120 points required for progression through a year of a degree program. In all degree programs, 10 credit points equates to 3 hours of formal class time, per week, per semester.

Classes consist of a weekly two-hour lecture for all students followed by a one-hour tutorial class for groups of up to 30 students. Model making (as described herein) has replaced the use of 'formal' laboratory classes since 2001. Prior to 1998, lectures were one hour and tutorial/laboratory classes were two hours. The content as shown in the syllabus provided might well be described as classical introductory statics and internal mechanics of solids.

The approach utilized in introducing model making was to incorporate at least one major project for each of the two semesters of Solid Mechanics A. Each semester students are required to research, design, manufacture and competitively test, a model that effectively encapsulates the theory presented in lectures.

This enables:

a) Every student to individually express their creativity and commitment to learning and gain reward for the time/effort spent (there are prizes awarded for the best models),
b) Students become caught up with the enthusiasm generated and 'feel good' about their successes/achievement,
c) Students to gain their first experience of the Engineering design process (albeit with the limited knowledge and information available to them as freshmen), and the need to achieve a desired performance outcome which mimics real world engineering
d) Utilisation of theory, contextualised within a structural model and encouragement for students to seek further information from a wide range of references both within and outside of the subject syllabus boundary,
e) A healthy spirit of competition to develop between students, to achieve the best possible strength to weight ratio for their model,
f) The completion of each semester with a fun-filled, highly motivated learning experience for all students with the controlled breaking of all models,
g) A deeper level of learning, despite the limited theory presented at first year level

The abbreviated syllabus for both semesters of "Solid Mechanics A" follows.

Semester 1	***Semester 2***
1. Force and resultant of several forces.	1. Plane / shear stress and strain.
2. Components of forces.	2. Hooke's law / Poisson's ratio.
3. Moments of forces.	3. Properties of plane sections – 1
4. Equilibrium of co-planar forces - 1	4. Properties of plane sections – 2
5. Equilibrium of co-planar forces - 2	5. Beam bending stress theory – 1
6. Pin-jointed Trusses	6. Beam bending stress theory – 2
7. Truss member forces - joint equilibrium.	7. Behaviour of axially loaded members
8. Truss member forces – via sections.	8. Short / long column behaviour
9. Beams.	9. Euler's theory for long column behaviour
10. Internal beam – Shearing Force.	10. Beam shear stress theory.
11. Internal beam – Bending Moment	11. Beam deflection theory.
12. Simple frames.	12. Beam deflection by integration.

Semester 1 Model

This is known as the “Paddle Pop ™ (stick) Bridge” model. (After the company “Streets Ice Cream Pty Ltd”, the makers of an iced confection known locally as “Paddle Pops” and the prime sponsor of the annual Australia-wide competition of the same name for freshman Engineering students. A “Paddle Pop” iced utilises a single pine ‘stick’, 100mm x 10mm x 2mm, as support for the surrounding frozen confection.) It incorporates 8 of the 12 weekly topics covered in semester 1 of the course.

Objective:

To design, draw, construct and test a model truss bridge to achieve a maximum structural ‘efficiency’ over a 500mm span supporting a single central load within the specifications, rules and regulations as provided. A ‘professional’ report must accompany the model. See Figures 1 through 4 for relevant photographs.

Specifications and testing:

1. Model bridges are to be of the under-slung truss type. Any shape/member configuration may be used provided the resultant model fits within the stated dimensional parameters.
2. Testing of models under a central load is in two parts whereby models that pass a simple load test of supporting a freely suspended 30kgm mass at mid-span go into the pool of ‘proofed models’ for final.
3. Final testing utilizes a calibrated Instron ™ testing machine via a loading ‘head’ which is capable of limited rotation in the plane perpendicular to the model.
4. The load carried by each model at ‘collapse’ will be recorded and divided by the mass of the model to achieve a strength to weight efficiency ratio.
5. Collapse is defined when either the model cannot support any further increase in load or the deflection at the load point exceeds 30mm.

Material limitations:

- 275 standard, untreated, pine ‘paddle pop’ sticks as provided and a 250ml bottle of PVA adhesive as provided. No other materials may be used.
- No treatment may be applied to the sticks (Sanding may improve adhesive bond.)
- Sticks may be cut/glued in any shape/way to form the truss members and connections.
- The models must span a clear distance of 500mm with approximately 20 to 25mm end support length. This means the total length of a model must be between 540 to 550mm exactly with a clear span portion of 500mm.
- No part of a model may project up above the level of the support frame by 20mm nor down below the level of the testing frame top by more than 110mm.
- The width of a model must not exceed 110mm at any point.
- Contact between the model and the testing frame to be only at the support tops.

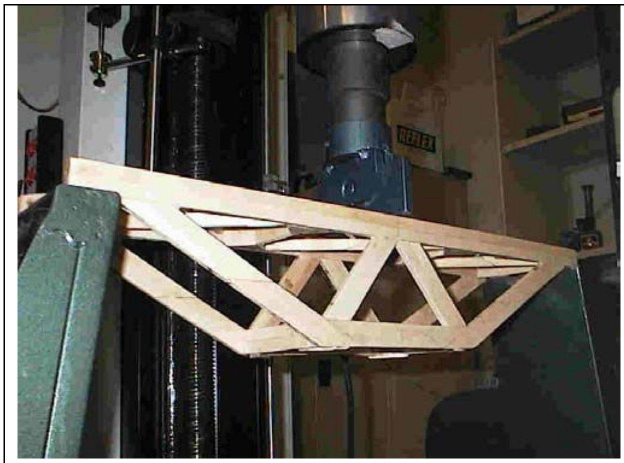

Figure 1. Typical under-slung truss model

Figure 2. Loading frame utilised

Figure 3. A final testing session in progress

Figure 4. Comparing notes on models awaiting test

During fabrication and prototype testing at home, interesting (and unexpected) techniques and locations are employed by students (Figures 5 through 8).

 Figure 5. Fabrication 'techniques' vary	 Figure 6. Prototype testing 'techniques' also vary
 Figure 7. Prototype testing (with human loading as added dimension!)	 Figure 8. Fabrication via the kitchen table

Report:
Students prepare a report which

- explains the reasons for the choice of the truss shape/configuration. Hint: Seek and read books on trusses/bridges, solid and applied mechanics. Carry out an Internet search etc. Focus on the reasons for choosing the particular truss shape,
- includes a printout from the program MDSOLIDS ™ for member forces of the truss configurations you considered (at least 3 alternate configurations) and your 'final' configuration.,
- provides a set of your own calculations (using both the method of joints and of sections) for truss member forces for the final truss configuration assuming the truss supports a nominal 50kgm mid-span mass.

Semester 2 Model(s)

There are alternate primary models and one minor model.

Secondary (minor) model- Shear strength of PVA adhesive

This consists of an investigation of the failure characteristics and strengths of "Paddle Pop" sticks bonded with PVA adhesive in simple single and double shear. A brief experimental format is suggested to students, and they are required to devise the loading mechanism(s) to achieve a gradual increase in load (to breaking point) for a joint under test. As Figures 9 and 10 show, students find highly inventive ways to test their bonded joints. This incorporates the theory in weeks 1 and 2 of the semester.

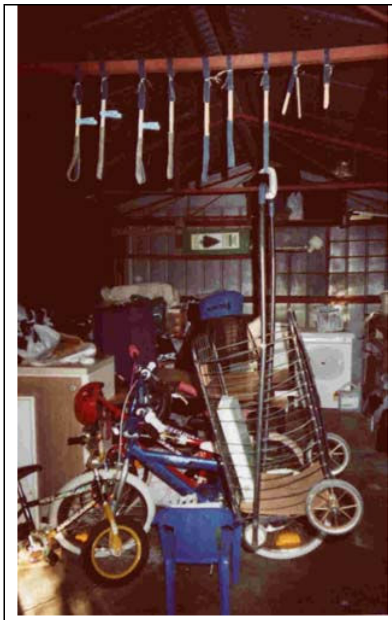

Figure 9. Ingenuity in loading

Figure 10. A more conventional loading setup

Alternate Primary (major) models

Balsa-wood Model Column

This incorporates theory from weeks 3 to 4 and 7 to 9 of the semester.

Objective:
To design, draw, analyse and construct a model column made from balsa-wood, PVA bonded sheets, to achieve maximum structural 'efficiency' i.e.: maximum value of axial load cf. mass of column, within specifications as provided.

Specifications and testing:

1. Column will have a fixed base - pinned top connection/support type.
2. Any shape/cross-section configuration may be used, provided the resultant model is constructed upon and fits within the two 75mm square end plates, as provided.
3. Only balsa-wood and PVA adhesive may be used to construct the column.
4. Model testing will utilize a calibrated Instron ™ testing machine with load applied axially and uniformly through the 75mm end plates. The loading 'head' at the top of the column will be capable of rotation in any direction.
5. The load in N carried by each column at collapse will be divided by the mass of the model minus the weight of the end plates to achieve a strength to weight ratio.
6. Collapse is defined when either the model cannot support any further increase in axial load or the lateral deflection at the mid-height exceeds 30mm.

Material limitations:

- Standard, untreated, 915mm long x 75mm wide sheets of balsa-wood of any of the following thicknesses - 1mm, 1.5mm, 2.5mm, 3mm, 5mm. PVA adhesive (100ml tube should be adequate). No other materials may be used.
- No treatment or coating is to be applied to the balsa-wood sheets, except for lightly sanding sheets to improve adhesive bonding.

- Sheets may be cut and bonded together in any configuration to form the column.
- Models must have an exact overall total length of 750mm.
- No part of a model may project outside from a 75 x 75mm square at any point along the column.

Figure 11. Class models awaiting test.

Figure 12. Torsional failure exhibited

Figure 13. Crushing failure exhibited

Figure 14. (Euler) Bucking exhibited

Report:

A report must accompany each model submitted. The report should:

- Explain why the column cross-section chosen was selected. (Research column types in the campus library and/or conduct an Internet search.) Focus on reasons for choosing a particular cross-section shape/size.

- Include calculations for column crushing load and the theoretical EULER buckling load for your column. Also, comparative analyses of at least three alternative cross-sections you considered.

Figures 11 through 14 show typical model columns failing under test.

Balsa-wood Model Beam

This incorporates the theory from weeks 3 to 6 and 10 to 12 of the semester.

Instructions:

Imagine yourself as an 'Engineer' ……… working with a partner,

1. You are to design, draw and fabricate a model beam.
2. Beams must be made from balsa-wood sheets with PVA adhesive, and is required to span 500mm and support a load at mid-span with less than 50mm deflection collapse.
3. Beams must have a 25mm support length at either end and should not be wider than 100 mm nor deeper than 80mm at any point along the beam.
4. The load at failure will be divided by the mass of the beam to gain an index of efficiency that will contribute 50% towards your final assessment for this project.
5. You must provide a set of calculations and sketches including:
   - bending moment/shear force diagrams for a nominal load of 500N
   - maximum bending stress and shear stress, in your beam for the nominal load and what you estimate will be the value of the failure load
   - an estimate of the elastic modulus for balsa-wood so that you can predict the deflection at mid-span under a 500N load (on the day of the final test this will be recorded) and your estimate will be compared with the measured value
6. In the report that accompanies your model you must explain why you chose the beam configuration and how you think it will fail (you should give rational reasons for this supported by data). Your research on beams should be included as an appendix to your report.

Material limitations:

- balsa wood, cut from sheets of up to 5mm thickness, (thicker sheets may be achieved by bonding 2 or more thinner sheets together)
- PVA adhesive as for the Semester 1 "Paddle Pop" bridges

Figures 15 through 18 show typical model beam failure modes.

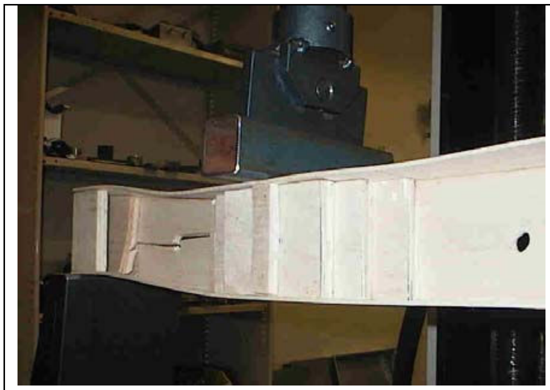

Figure 15. Web shear failure

Figure 16. Tension flange failure

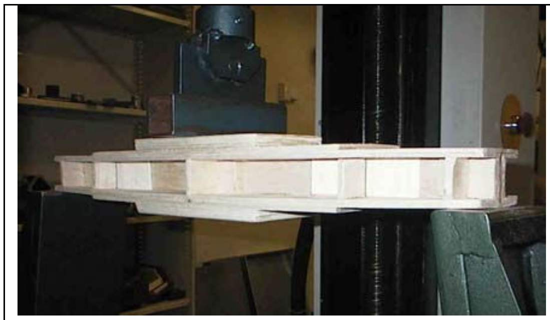

Figure 17. 'Flange Plated' I beam

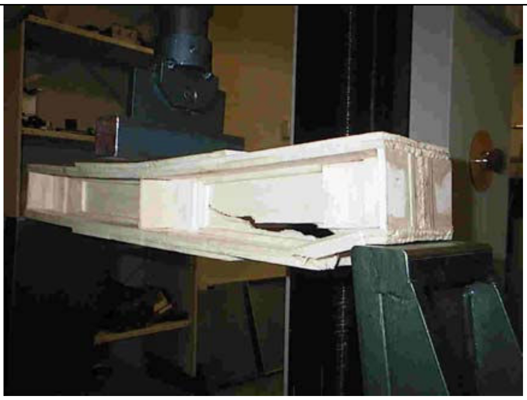

Figure 18. Web/flange failure

3. Outcomes following the introduction of model making/breaking:
There were expected and some unexpected benefits following the introduction of models to Solid Mechanics A.

1. During a semester, students become excited as their model constructing activity commences/proceeds, They begin to seek answers to questions that lead to later subjects in their courses. Their 'motivation' level rises dramatically.
2. Since models are fabricated/prototypes tested at home, a student (in this way) exposes relatives, friends and family acquaintances to the 'process' of engineering design. This assists students in validating Engineering as their chosen career.
3. In 2001 and again in 2002, significant numbers of students sought to enter the annual Australia competition for "Paddle Pop" model bridges in Sydney. (In both 2001 and 2002, this competition was won by freshman students taught by the author. Figures 19 through 22 show aspects of this annual competition.)
4. Progression records show that for the years 1998 through 2000, the percentage pass rate for students at their first attempt of Solid Mechanics A averaged 40%.
5. In 2001 all (remaining) laboratory classes were replaced in both semesters with model making projects. From 2001 to 2003, the progression rate has risen each year to the present (2003) level of 63%, which matches that of other 'difficult' freshman courses such as Physics and Mathematics.
6. Assessment of the course by students is punctuated by strong and widespread positive comments for model making and the learning and motivational benefits these projects are able to offer.

Figure 19. Models for the 2001 Annual "Paddle Pop" competition.

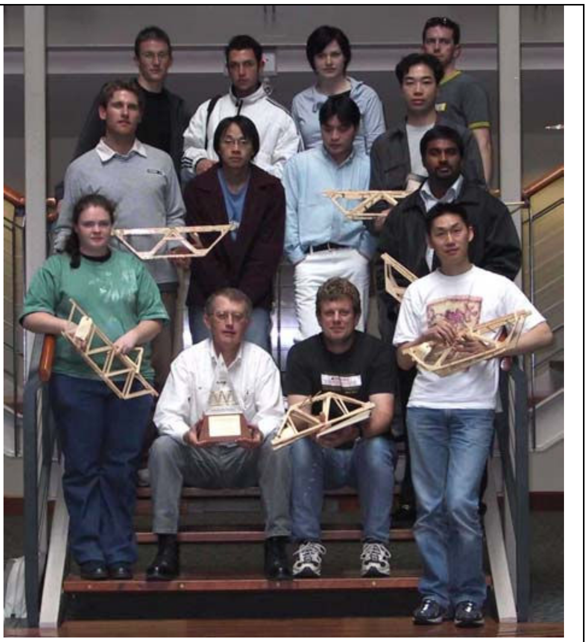

Figure 20. Victoria University's 2001winning team.

Figure 21. 2002 "Paddle Pop" competition in progress

Figure 22. Victoria University's 2002 winning team.

4. Conclusions

Individualized and relevant assessment tasks for students are prized both by students and educational theorists. The author has evolved and utilizes a personal philosophy of Engineering educational instruction that encapsulates 'experiential learning' via the making and breaking of structural models in a freshman Engineering Statics course.

For freshman courses with large numbers of students, the logistics and resources demanded often mitigate against the use of such individualized tasks. By simplifying the tasks and re-directing the fabrication phase to occur outside of and separate from University facilities, this enables students to 'see' the theory of Statics "in practice" in a memorable yet manageable way.

The reward for students is a strong foundation for the remaining years of study and the career that will follow.

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Biographical Information

Ian Campbell is a Senior Lecturer and Course Director for the degrees in Architectural and Building Engineering at Victoria University, Melbourne, Australia. He holds a degree with honours in Civil Engineering and a Master of Science degree in Building Services (Engineering) with distinction. He has taught Engineering students for 30 years and recently introduced the first Australian degree in Architectural Engineering (2001).