INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'09
24 - 27 AUGUST 2009, STANFORD UNIVERSITY, STANFORD, CA, USA

FAILURE - PREDICTION COMPETITIONS TO DEVELOP STRUCTURAL DESIGN SKILLS

Bruce Field
Monash University, Australia

ABSTRACT

At some stage in their education, a mechanical engineer learns how to analyze a range of structural elements, such as beams, columns, shafts, welded and pinned joints. Separately, they learn how to conduct a static load analysis. A deeper understanding of these concepts can be gained in a single project during which an artifact is loaded to destruction.

Students are supplied with incomplete information about the artifact, and may have access to the actual device. They conduct a load analysis, identify suitable modeling equations for the different parts of the artifact, then investigate the plausible failure modes, systematically eliminating modes and locations of high strength so they can identify the location and load that constitutes ‘failure’.

The author has been setting this type of project for a design course in the BE program at Monash University since 1992, and has identified several simple rules that can be applied when such projects are set, helping to ensure that the outcomes are satisfying and educational.

By presenting this project as a competition, students become motivated and curious to find out how their otherwise theoretical studies actually apply to real artifacts.

Keywords: Machine design, design competition, structural distillation, failure analysis

1 INTRODUCTION

Mechanical engineers must be able to design economical static devices that can withstand a variety of loads without failing. Undergraduate courses in fundamental and applied stress analysis develop some of the required skills needed to predict stress levels at selected points in a mathematically-modeled artifact. Other courses, typically delivered by design engineers, apply similar theories to practical components and joints in order to ensure safe structural behavior. At some stage in the trainee engineer’s education, skill in translating between a proposed or actual artifact and its mathematical representation (a task called ‘structural distillation’[1]) is developed. Most of the pedagogy for learning these structural analysis skills involve classroom activities and practice tasks from textbooks [for example, 2]. For some engineering students, most things learned from textbooks or in the classroom are ‘theoretical’, and un-motivating, while even the most ‘academic’ engineering student may wonder if their careful calculations represent anything that is real.

It can be a straightforward task to predict the stress or deflection at a nominated location in a loaded object. It is entirely another task to predict the external load at which the peak stress or deflection reaches a specified level (the specified level may be defined as the stress or deflection at which failure is said to have occurred), because the prediction firstly involves the identification of the region at which the peak will occur, before applying the appropriate analytical tool. In other words, the solution is only achieved when it is proven that the failure criterion will not be met earlier at any other point in the object. This feature means that the problem-solver must possess a deeper understanding of the stress distribution in the object than would have been required to only predict the stress or deflection at a pre-defined point.

In moderately complex objects, high levels of local stress may contribute to structural instability (such as with columns), or yielding/fracture by combinations of tension, torsion (shear), crushing and direct shear. In some of these cases, the locations of the peak stresses, and their relationship to external loads may not immediately be obvious. In other cases, counter-intuitive visual clues given by the shape of the object may lead to erroneous choices of load and stress patterns [3]. This gives the potential to construct learning tasks of varying complexity for load and stress analysis where a real artifact is loaded to destruction, and the learner is required to predict the loading and location of the failure site. By determining the ‘solution’ during a public destruction of the artifact, any notion of the task being a ‘theoretical’ project is dispelled. By encouraging a competition to predict the failure, the learning experience can be enhanced [4].

The author has been setting such tasks at his university since 1992, and has learned by experience their educational potential and their possible pitfalls. This paper describes some of the structural problems that have been used, together with the simple ‘rules’ that have evolved for setting successful tasks.

2 LEARNING OBJECTIVES IN STRUCTURAL ANALYSIS PROJECTS

2.1 Place of structural analysis project in the Monash design program

The mechanical engineering program structure at Monash University is described in Appendix A. During the second semester of the second year of the program, students enroll in Design 2, where they undertake a minor project, followed by a major team project.

2.2 Structural analysis task objectives

The minor project in Engineering Design 2 during which a real artifact is to be analyzed in order to predict its failure is formulated to fulfill particular educational objectives. Those objectives, in approximate order of decreasing importance to the project are:

1. Advancement of skill in structural distillation: the creation of analytical models that are fair representations of the real artifact (for example, the identification of end constraints and effective lengths of column members comprising one single bolted joint and one rod-end).
2. Load analysis: the prediction of the relative loads (forces, torques and moments) that are appropriate to the analytical models of the various parts (for example, moments on beams, axial forces on columns, shear forces on pinned joints and loading combinations on welds).
3. Reinforcement of contemporary studies: for this course, the formal analytical tools for the design of joints (welded and pinned) is separately lectured and learned by conventional textbook problems.
4. Identification and review of prior studies: previous course content is to be integrated (for example, basic free body diagrams, the conversion of hardness data to strength properties and the calculation of second moments of area).
5. Independent learning of untaught knowledge: some tools needed to solve the problem are not part of prior or current courses so must be self-taught (for example, in most projects, the load is applied through a power screw, but the analytical models of power screws, including the influence of friction, are not formally taught to students).
6. An appreciation of the sensitivity of assumptions: the effects of imperfections or non-ideal geometries must be considered (for example, incomplete welds, the actual strength of *in situ* weld materials, the influence of friction in a bolted shear joint or load-sharing in redundant supports).
7. The development of teamwork skill: this minor project is normally used as a means of allowing student teams to self-form and to identify individual strengths and weaknesses prior to the teams’ undertaking the subsequent major design project that is worth five times more credit toward a student’s grade.

2.3 Pedagogy

It is recognized that students have preferred ways of learning, and that those preferences can be measured. One of the original instruments for categorizing learners was Kolb’s Learning Style Inventory (K-LSI)[5], that identified four basic styles: (1) Diverger, (2) Assimilator, (3) Converger and (4) Accommodator (Figure 1).

It is apparent that Kolb’s types 1 and 4 learners prefer the use of the right brain component skills of ideation and intuition respectively, validated with concrete outcomes, while the types 2 and 3 prefer logical decision-making and abstract concepts: left brain skills. According to Kolb, most learners tend to display strong preferences for one or a pair of the styles, and that the styles are diametrically opposed, such that pairings of types 1 and 3, and 2 and 4 are rare.

Students in Australia follow the international trend in learning preferences, with about three quarters of engineering undergraduates being either type 2 or 3 [6, 7]. These students are most comfortable with structured lecture programs and abstract theory (type 2 learners) supported by similarly structured tutorial problems where the logic is applied to practical applications (type 3 learners). While these modes of teaching are commonly used in design classes, as well as in the majority of the engineering sciences in Australian universities, design problem-solving also demands skills that types 1 and 4 learners find most comfortable: the generation of ideas and the achievement of concrete outcomes, respectively. It appears that learning outcomes in design education engage all four learning styles at various stages. The rarity of students who are comfortable with all four learning styles means that most students will find at least one phase of their design learning relatively uncomfortable, indicating that the distribution of preferred style may influence the grades in design courses differently from non-design courses taught by classical methods.

There is some evidence that learning is maximized for most learners (irrespective of their preferred style) when a learning experience combines all four learning preferences [8]. The author and his colleagues have observed positive learning experiences from the use of artifacts when learning about injection molding [9]. Therefore the combination of divergent tasks (identifying plausible failure sites), assimilation tasks (analyzing the plausible options), convergent tasks (selecting the single likely failure site) and accommodation tasks (observation of the concrete outcome) in a failure prediction project has a sound pedagogical basis.

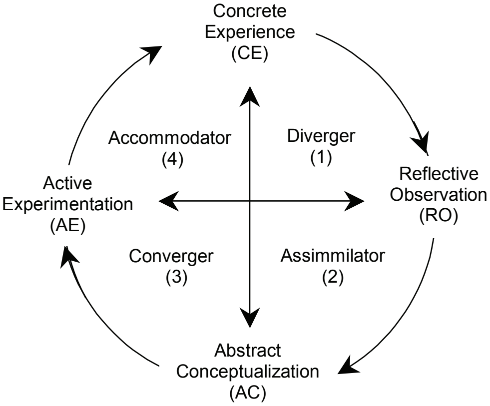

Figure 1. Kolb's four-staged learning cycle and the four learning styles

3 SUCCESSFUL STRUCTURAL FAILURE PROJECTS

Small projects in which student teams (or individuals) competitively predict the failure of real artifacts have been running at Monash University since 1992. The program structure in mechanical engineering at Monash has varied during that period, and student numbers in the relevant design course have grown from 80 to 160, so the artifact-failure project has necessarily been adapted to the changing circumstances. However, those projects have tended to fall into three types: artifacts designed by students for other purposes, commercial artifacts and specially-designed artifacts.

3.1 Using student-designed artifacts

In the early 1990's, the course structure for the predecessor of Engineering Design 2 contained two medium, and one small project. In the first project, teams of six students spent 6-7 weeks on an open-ended design task that led to their specifying a mechanical artifact in a formal report including a full set of manufacturing drawings. The second group project (with a focus on a design based on an aspect of fluid mechanics) ran for the remaining six weeks. For the third (small) project, running in parallel with the second project, students were individually required to predict the failure location and loading for a design from the first project that was selected and professionally manufactured in the engineering workshop.

The first of these small projects, in 1992, was the failure prediction of a special small crane to be used for loading electric wheelchairs into a motor vehicle. At the end of the earlier design project, the author selected one design from the 15 designs submitted by student teams. The chosen design had several features that made it suitable for use as a structural failure project:

1. Students' design drawings were relatively complete and of a good quality,

2. The components of the design were easily obtained or manufacturable in the engineering workshop,
3. The design contained several straightforward structural components and loadings, such as combined torsion and bending, welds in offset bending, and double shear pins that were the subject of study in the current course.

During the following six weeks while the crane was being manufactured, the original design team was required to report weekly on progress, and in particular to report where the manufacture had deviated from their original design. Copies of the original workshop drawings were made available to the students, and these drawings were updated as required. Lectures were held on the analysis of various pieces of machine structure, such as welds and axles, and all students were required to submit calculations on those aspects of the artifact on three intermediate occasions. Just before the last session in the semester, students submitted a single-page document specifying their prediction of the region and load that would bring about that failure. Figure 2 is the setting for the final session, with the manufactured crane ready for testing. In this image, the student team responsible for the design is presenting their last oral report, and the workshop technician responsible for the manufacture is also present, sitting at the end of the first row. Since 1992, the workshop staff have remained very interested in the outcomes of this type of project.

Figure 3 is a copy of a slide prepared for the final class session. It shows the range of predictions made by the 104 students in the course. Seven different modes of failure were predicted. Figure 2 also shows the distribution of loads predicted to cause failure. The range, from less than 3 kN to more than 60 kN raised an embarrassed giggle. In this instance, the device failed at the welded joint predicted by 15 of the students, with a load of 35 kN measured by the load cell visible at the lower left in Figure 2.

Figure 2. Student-designed crane under destructive test.

3.2 Using commercial artifacts

From the late 1990s, various changes in the program at Monash University led to a re-arrangement of the project work in Engineering Design 2. The two medium design projects were amalgamated into one, so that a more complex task could be undertaken, and this was scheduled to take 8-9 weeks of work. There was no longer sufficient time to ensure that a student design could be selected and built before the end of the semester. To gain a similar educational outcome, the small structural failure project was retained, but was based on available commercial artifacts. Initially, this project ran in the last 3-4 weeks of the semester and gave a relaxed atmosphere to the last lecture where the item was tested, but more recently, the project has begun the semester's work so that teams could form and become effective before they began their major project.

Figure 4 is an annotated image from a project where an inexpensive wheel-puller was used to load a fabricated item that contained two different types of weld and a bolted joint in bending. During the project, students had access to the puller assembly and several dismantled pullers so they could obtain relevant measurements. Figure 5 is a summary of student predictions for this project. Notably, 33 of the 55 project teams for this task correctly predicted the weld failure, although, once again, the spread of predicted torque for causing the failure was very large, ranging from less than one, to over 2000 pounds-feet! The peak torque (defining the failure) was 44 pounds-feet, and it can be seen from Figure 5 that most teams significantly underestimated this value. Their error generally arose from an underestimation of the effect of friction in the main screw, mainly because as the mechanism became more heavily loaded, slight manufacturing asymmetries placed some bending stresses onto the screw, which then increased lateral loading (and therefore the friction) in its thread.

Other commercial artifacts used for this project include a sash cramp (Figure 6) and a pipe clamp.

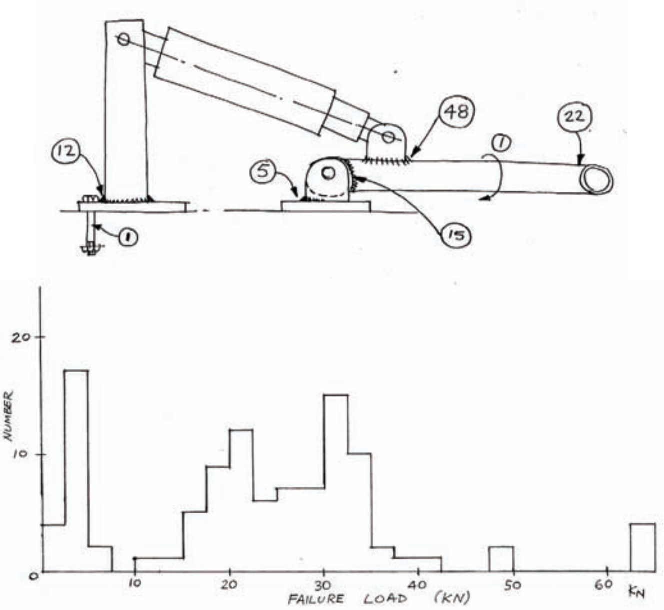

Figure 3. Slide presented and discussed with students before the crane (Figure 2) was destroyed

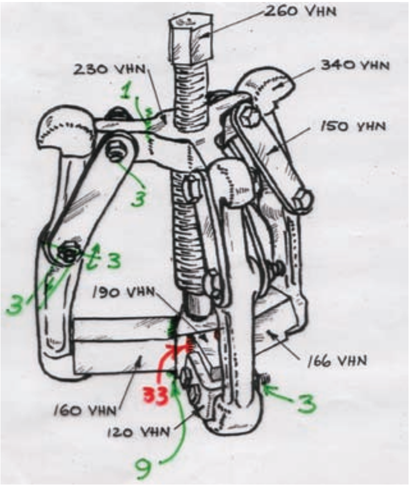

Figure 4. Task graphic of a wheel-puller with fabricated item, Vickers Hardness Numbers for most parts and a summary of student predictions of failure sites

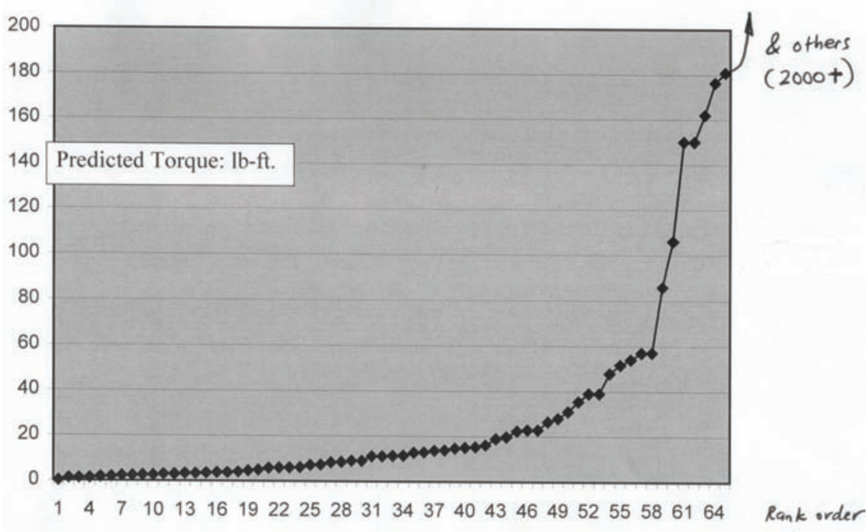

Figure 5. Torque predictions for failure of the wheel puller. This means of presentation of data to the students was simple to construct from a spreadsheet, but did not have a high impact in the classroom. A histogram (e.g., Figure 3) is more informative,

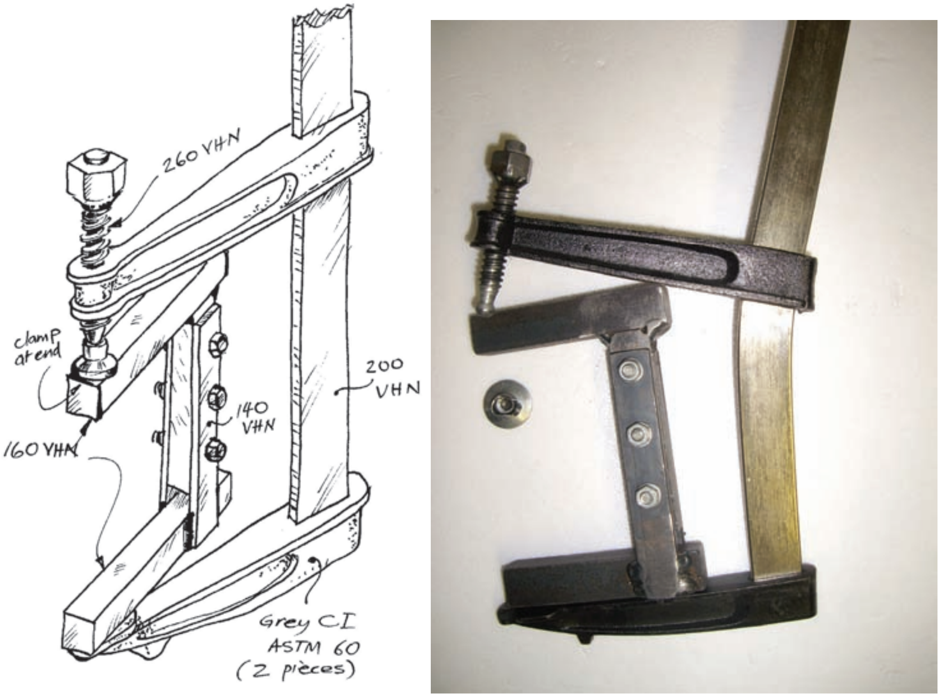

Figure 6. Modified sash cramp with a nut welded onto the screw, and a fabricated 'C' piece with two types of welded joint and a triple-bolted joint in bending. The various notes to students (left) include Vickers Hardness numbers, material, and location of loading position. The failed cramp (right) became unstable before the upper cast iron arm cracked.

3.3 Using specially manufactured artifacts

In recent years, specially fabricated whole frames and structures have become more commonly used for this project. This has facilitated control of the failure mode and has enabled the integration of a larger range of joints and potential failure sites. During these projects, students have access to the pre-made artifact, and have access to the original detail and assembly drawings of the components, plus hardness data for most of the steel parts. No destructive testing is allowed on any parts, but students may undertake some non-destructive tests, such as experiments to find the value of the coefficient of friction between parts.

Figure 7 is one structure that was made as a 3-D item in order to produce a combination of bending and torsion near a central weld. The central column made from a rectangular aluminum bar had a rod end at the top and a clamped bolted joint at the bottom. The tensioning device was a long screw (similar to that on the left-hand end), with calibrated strain gauges arranged to indicate the tensile load.

Figure 8 is a planar (symmetrical) frame from 2006 that was loaded by turning the nut welded onto the end of the long threaded rod. In this structure, the two steel straps with the triple-bolted attachment also bent about 10 degrees plastically before the main pinned joints sheared off. Student predictions were summarized in a graph (Figure 9) for presentation as an overhead projection slide before the frame was loaded. The logarithmic scale of predicted failure torques was uncovered after the histogram was shown, and the class then discussed the practical meanings of torques less than 2, and more than 10,000 Nm.

The project for August 2009 (Figure 10) is visually similar to that of 2006 but it has one important difference. In 2006 the structure was still rigid even without the loading screw. Consequently, using the separate detail drawings of the parts, students could draw the structure in its assembled configuration, before conducting a 2-D loading analysis to determine the relative loads and moments at critical points. Most student teams let the tensile load (P) in the screw be an algebraic variable, then calculated the multiples of P at various bolted joints and for bending moments. However, the 2009 frame is a 4-bar mechanism without the loading screw. Therefore students have to determine the equilibrium geometry of the structure before they begin to analyze the loads.

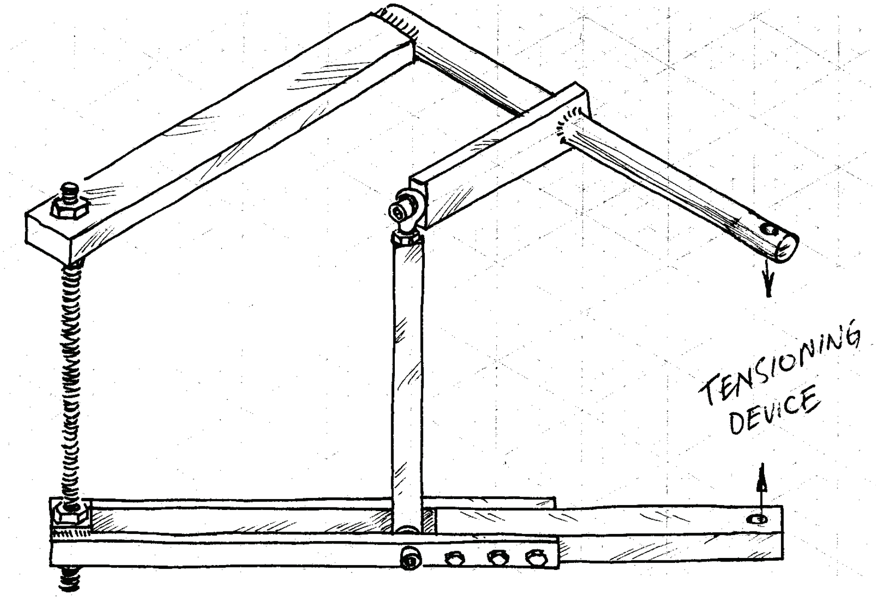

Figure 7. Image from a project with a fully fabricated artifact. The central column buckled although there was also noticeable plastic deformation in the middle of the top circular bar.

Figure 8. Fabricated frame from 2006 project: the failure occurred when the screws at the ends of the central columns sheared. The steel straps deformed plastically (right).

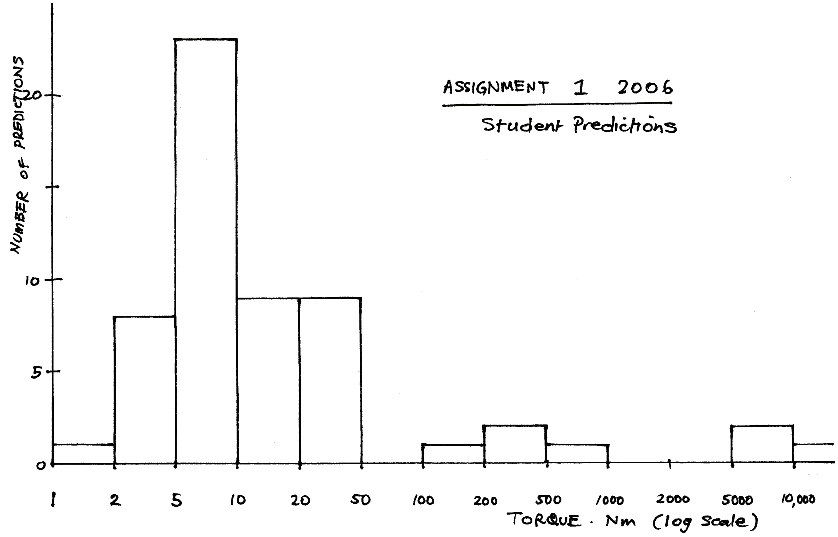

Figure 9. Graph of student predictions for the failure of frame in Figure 7. The predictions were extracted from team submissions, and the graph was drawn immediately before the frame was loaded. The measured failure torque was 9.8 Nm.

4 GUIDELINES FOR CONSTRUCTING STRUCTURAL FAILURE TASKS

After some fifteen years of developing structural failure tasks for engineering students in their second year of mechanical engineering, a number of guidelines have emerged.

1. Confine yielding to small regions.

   It is difficult to predict the loadings at critical points in the structure if the geometry of the structure alters significantly as it is loaded. Since most common engineering materials used in fabrication are fairly ductile (with perhaps 20% elongation at fracture), the overall geometry can change excessively if large areas of material reach their yield points. Consequently, the peak stress in long beams, shafts subject to torsion, and in simple tension members (such as the long threaded rod in Figure 7) should be kept below the Yield Point unless the parts are made of brittle materials or unless their elongation does not affect the overall geometry. Small ductile parts can fracture since their plastic distortion is also small. For example, the welds in Figure 4 tend to fracture at the heat –affected zone, and the column bolts in Figure 8 sheared off suddenly because the shear stress was distributed fairly evenly across the small cross section. Apart from affecting the thread engagement, power screws like those in Figures 8 and 10 can be satisfactory sites of tensile failure because their ductile stretch does not affect the overall loading geometry. The circular beam in Figure 7 bent and twisted plastically, resulting in a permanent skew of some ten degrees between the initially parallel bars welded to it before the column buckled. Fortunately this distortion did not seriously affect the loading geometry. The sash cramp's steel bar in Figure 6 bent outwards by some ten degrees before the cast iron fractured, and this distortion meant that the fabricated artifact was almost ejected from between the jaws. It also placed a considerable bending load on the power screw, meaning that there was a real possibility that the screw would bend too.

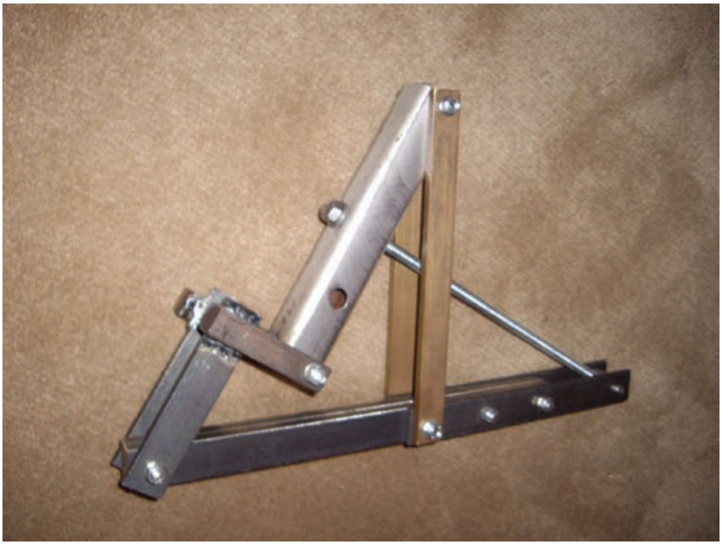

Figure 10. Frame for 2009. The structure is a mechanism until the diagonal power screw is tightened, and students are required to determine the equilibrium configuration.

2. Beware of elastic instability.
   The columns in Figures 7, 8 and 10 are plausible failure sites (deliberately made asymmetrical in cross section and in their end constraints) that would sustain an increasing load up until their sudden failure. However, the fabricated 'C'-shaped 'column' in Figure 6 was not stable. The top end was a ball joint (within the clamp pad), and at the bottom, the support was like a built-in end for the initial loading. As the screw load increased, the clamp's upright steel strip was able to bend and twist, shifting the clamp pads out of alignment. In this position, the 'column' end supports both behaved as ball joints, and the resulting four-member rectangular structure (comprising the two cast arms, the fabricated artifact and the steel bar) continued to twist at a steadily increasing applied load. The test had to be stopped because the fabrication was about to be ejected. The artifact testing was subsequently continued with guide bars clamped to the cast iron parts to prevent any further twist.
3. Ensure accessibility to adequate data on the materials.
   If the hardness measures of the fabricated steel parts are made available, for example as shown in Figures 4 and 6, students need to convert the information into the Ultimate Tensile Strength of the steel. They may then be able to obtain an estimate of the likely yield point, by using various rules of thumb, or in some instances, they may be able to estimate the grade of steel used in the artifact. By selecting screws and bolts whose heads are marked with the standard SAE grading, students can obtain reasonable data of the strength properties. Other materials, such as Aluminum and

brass grades should be specified in the project, like that as shown for cast iron in Figure 6, or determined in a separate demonstration. Some commercial artifacts may present a difficulty. One approach is to test such artifacts to destruction and calculate backwards to obtain a material property. Alternatively, it may be prudent to ensure that a component with predictable properties is the first to fail.

4. Define ‘failure’ unambiguously.
   If the project is run as a competition, it is necessary to have a clear numerical criterion for failure. For the projects described in this paper, the ‘failure’ was defined as the first occasion when the applied load reduced during the test. This allowed us to use a portable peak-reading voltmeter attached to a load cell (or strain gauges) to detect and record the peak. In some cases (e.g., Figure 7) strain gauges were attached to a power screw to measure load. More commonly, the torque on the loading screw has been measured with a calibrated torque wrench (Figures 4, 6, 8 and 10). Clearly, the load should reach a sharp peak. Preferred failure modes are (i) weld fracture (Figure 4), (ii) shear of pins (Figure 8), (iii) column buckling (Figure 7) and brittle failure (Figure 6) because the load drops off rapidly (sometimes to zero) at such catastrophic failures. Competition winners are normally declared as the team that (i) nominates the correct failure site and then (ii) has the closest prediction to the measured failure load.
5. Control the opportunities for experimenting.
   It is desirable to limit the possibility that students can find the failure by pre-testing the artifact. Some students with a workshop may be able to replicate the artifact, or may locate a copy of a commercial artifact. However, since the best way of grading such projects is to consider the accuracy and breadth of predictions (the thoroughness by which students discard potential failure sites), such experimental verification would normally lead to a very restricted report and lower grades. Nevertheless, it is best to confine rewards for correct failure predictions to a prize, rather than an improved grade. Some limited experimentation on artifacts, such as a ramp test to determine the value of the coefficient of friction between parts, can be encouraged.
6. Pre-test if possible.
   If the artifact is inexpensive to purchase or make, it should be feasible to pre-test a duplicate to confirm that the failure satisfies the appropriate criteria, such as occurring with minimal plastic deformation, or that it occurs in a region that students should be able to analyze. Some caution is needed in the case of inexpensive commercial artifacts, since low standards of quality control may produce unexpected outcomes. A sample of the cheap commercial sash cramp (Figure 6) was pre-tested, and the cast iron fractured in the lower arm with only minor deformation in any of the parts. However, during the classroom test the applied torque reached twice the earlier value (the pre-test failure was apparently located at a flaw), and this led to significant plastic bending and twisting in the steel bar, and the loading became unstable.

5 CONCLUSION

A project in which engineering design students attempt to predict the location and magnitude of loading needed to destroy a simple static artifact creates a fairly simple and valuable learning task. With a little forethought, it is possible to select or manufacture an artifact that contains a range of joints and structural elements, and which will fail catastrophically in a reasonably predictable way.

Students can be provided with some data (such as workshop drawings), or none (such as no information about the bolts used in a structure), in order to address various learning objectives.

The project is real, in that ‘the answer’ is found experimentally at the end of the project. With care, the experiment can be performed in a normal lecture room, and at this event, it is appropriate to discuss strategies or common mistakes. By making the prediction competitive, with a modest prize available, some variety is introduced into otherwise conservative teaching practices.

REFERENCES

[1] Samuel, A.E. and Weir, J.G. *Introduction to engineering design*. 1999 (Butterworth-Heinemann, Oxford)

[2] Juvinal, R.C. and Marshek, K.M. *Fundamentals of machine component design*. 2006 4th Edn (Wiley, NJ)

[3] Field, B.W., Burvill, C.A. and Weir, J.G. Student misconceptions in engineering design. *Int. Conf on Engineering Design, ICED’01* Glasgow, Aug 2001, pp253

[4] Churches, A. and Magin D. Student design and build projects revisited. *International Conference on Engineering Design ICED'05*, Melbourne, Aug 2005, Paper 128.61
[5] Kolb, D.A., *The learning style inventory: self-scoring test and interpretation booklet*. 1985 (McBer and Co. Boston, Mass)
[6] McCarthy, B. *Hemispheric Mode Indicator*. 1986 (About Learning Inc, Wauconda, Il)
[7] Lumsdaine, M. and Lumsdaine, E. Thinking preferences of engineering students: implications for curriculum restructuring. *Jnl of Engineering Education*, Vol 84, 2,1995, pp 193-204
[8] McCarthy, B. A tale of four learners, *Educational Leadership*, Vol 54, 6, 1997, pp46-51
[9] Field, B., Burvill, C. and Alirezaee, T. Using 3-D models to train engineering designers. *International Conference on Engineering Design ICED'09*, Stanford, Aug 2009, Paper 184
[10] Monash University, *Undergraduate handbook*. http://www.monash.edu.au/pubs/handbooks/undergrad/eng-0032.html
[11] Monash University, *MEC2402 Engineering Design 1*. http://www.monash.edu.au/pubs/handbooks/units/MEC2402.html
[12] Field, B.W. The Australian/New Zealand Warman design competition. *International Conference on Engineering Design ICED'97*, Tampere, Finland, Aug 1997, pp3/419-422
[13] Monash University, *MEC2406 Engineering Design 2*. http://www.monash.edu.au/pubs/handbooks/units/MEC2406.html
[14] Field, B.W. Learning economical manufacturing methods and reducing mental set using value analysis in a PBL environment. *AEESEAP Jnl of Eng Education*, Vol 23, 1, Sept 1993, pp34-40

Contact: Bruce Field
Monash University
Department of Mechanical and Aerospace Engineering
Wellington Street
3800, Clayton
Australia
Phone +61 3 9905 3518
Fax +61 3 9905 1825
bruce.field@eng.monash.edu.au

Bruce Field is a professor of Mechanical Engineering and Discipline Leader (Design) at Monash University. Professor Field received his PhD in the field of machine failure diagnosis from the University of Melbourne, then practiced as a product design engineer for the Australian wool industry before taking faculty positions at Melbourne and Monash Universities. His main research areas range from Educational Psychology, through computer-aided learning tools and aerospace materials technologies to sports biomechanics.

APPENDIX A DESIGN COURSE STRUCTURE AT MONASH

A.1 Engineering program structure at Monash University

The undergraduate engineering programs at Monash University follow the conventional Australian structure of four years of full time study following twelve years of primary and secondary schooling[10]. Apart from focused study programs that allow students to qualify for two different undergraduate degrees in parallel (typically taking 5-6 years of study), the first year of the basic engineering program covers engineering mathematics and computing, some basic sciences (physics or chemistry) plus broad elective studies of various engineering sciences delivered by the specialist departments of Mechanical, Civil, Electrical and Computer Systems, Materials and Chemical engineering.

Those first year courses invariably focus on developing analytical skills in the various engineering disciplines, although there are minor design-and-build projects included in some courses (for example, spaghetti bridges, mousetrap racers, and simple robots) that allow students to exercise some imagination.

Students typically select their preferred branch of engineering toward the end of their first year, and then begin their specialization in the second year. During the first semester of the second year programs in Mechanical, Aerospace and Mechatronics engineering, students begin their first professional course in Design[11], contributing one quarter of their full time study workload.

Engineering Design 1 includes engineering graphics and sketching, manufacturing technologies and design methods. Team-based project work includes the national Warman design-and-build competition[12] and a traditional report-based open-ended design of a simple mechanical artifact. Most design students undertake a parallel course that includes fundamental stress analysis, which revises the first year course in Structural Engineering (that covered, among other things, load analysis and basic stress analysis such as slender columns, direct tension, shear and bending stress) before introducing the topics of combined stress (Mohr's circle), torsional stress, deflections and theories of failure (such as Tresca and von Mises). Bending and torsional stress theory is restricted to elastic analysis at this year level.

In the second semester of the second year of both Mechanical and Mechatronics engineering programs, students take a second design course[13] that occupies one quarter of the full-time program. Engineering Design 2 includes an introduction to 3-D CAD modeling but has a major focus on classical machine elements plus some additional, relevant studies in elastic stress analysis. The course topics include the design of welded, bolted and pinned joints, fatigue, shafts, bearings and the design or selection of other power transmission elements. Student teams currently undertake a major project (worth 50% of the course) of a design-re-design nature[14] that integrates learning from this course and previous studies from Engineering Design 1 and other courses, such as Engineering Dynamics.

During the first three weeks of Engineering Design 2, small teams of 2-4 students undertake a minor project (worth 10% of the course) where they are required to predict the location and loading that will cause structural failure of a real artifact.

Design courses continue in the third and fourth years of the engineering programs at Monash.

A.2 Design courses' learning objectives

Collectively, the separate courses in engineering design at Monash University have three generic learning objectives:

1. Knowledge of, and skill in using traditional and contemporary tools for engineering design,
2. Capability in solving large, complex engineering problems and
3. Engineers' knowledge and skills that are not otherwise developed in other courses.

'Design tools' include those of problem identification, ideation and creativity, systematic decision making, FMEA and value analysis.

'Problem-solving capability' includes the structure and management of teams plus, most importantly, the development of strategies for coping with non-linear, iterative, complex engineering problems.

Some of the peripheral skills developed in design courses at Monash include those of manufacturing technology, engineering graphics, 3-D (computer) solid modeling, load and stress analysis.

Although it may seem that 'design' dominates the second year engineering program at Monash (occupying 25% of the year), in reality, approximately half of the time spent in design courses is devoted to technical material such as stress analysis and manufacturing technology that is otherwise covered in non-design courses at other universities.

Increasingly, the design courses at Monash are required to develop skills in structural distillation so that undergraduates (and graduates) can translate between the somewhat analytical courses that utilize idealized models, and the artifacts that they have to design or analyze in the 'real world'.