The Pedagogy of creating a Mechatronic Product integrated with English Communication Skills for Teaching Design and Innovation to Engineering Undergraduates

Nickols F.M.J., Le Vasan M.

Abstract — *The newly formed Engineering Science department at the University of Brunei Darussalam (UBD) has recently initiated a 2-semester, 3-hour per week course entitled, "Engineering Design and Innovation". This year the students are tasked with designing, manufacturing and programming a working Mechatronic Potato Shaping machine that is required to form a potato into an 8-sided shape, known as a "Chateau Pomme-de-Terre", which is a shape similar to that of an American football. This paper describes the outline of the course and how students are initiated into the design and innovation of a Mechatronics machine together with the integration of the English Communication Skills course as a necessary scaffold to the required engineering genres related to reading/writing and oral/aural skills for efficient and effective execution of the course.*

Index Terms — Mechatronic engineering, mechatronic product design and innovation, mechatronic engineering pedagogy, potato shaping, vegetable forming, Chateau Pomme de Terre, English communication in mechatronic engineering, English for special purposes, (ESP).

I. INTRODUCTION

The analysis, design and construction of a mechatronic potato shaping machine is used in a first year undergraduate engineering science course entitled "Engineering Design and Innovation" in the University of Brunei Darussalam, (UBD). The course is being developed and delivered by the first author, F. Nickols. Running in parallel, and designed by the second author, M. Le Vasan, is an English Communication skills course that is specifically tailored for engineering students undergoing the design and innovation course. The courses are designed to expose students to (i) the challenges and fun of engineering design and innovation and (ii) the specialised English communication skills necessary for a Professional Engineer. The two courses run synergistically and concurrently and the authors refer to them as one course but for the purpose of this paper they will be dealt as two strands of the same course, i.e. Engineering Design and Innovation.

Engineering Design and Innovation is taught by tasking the students with designing and manufacturing a working potato shaping machine that forms or cuts a potato into a shape similar to an 8-sided rugby football or American football. Thus the students must deliver a product rather than a paper design. The course is being developed from scratch and at the time of writing the students have experienced 12 weeks of the 28 week course. The authors are of the opinion that "Engineering Design and Innovation" is most effectively taught by specifically focusing on the design and innovation of a mechatronic product because of the numerous engineering disciplines that are embraced by the field of mechatronic engineering. At this point it is worthy to comment on the many books now published that are concerned with the subject of Mechatronic engineering. It is usual practice that these books assemble together existing mature material based on sensors actuators, digital electronics and a microprocessor or microcontroller. The synergy of creating a mechatronic product that integrates the components of a mechanical system, an electronic system, a computer system and control software/information processing algorithms is, for most texts, insufficiently explained or demonstrated as case studies or integrated systems. As an improvement, to the state of the art, the first author suggests that the method advocated in this paper is suitable as an introductory course for Mechatronic Engineering because it addresses the limitations of existing texts on the subject. Furthermore, an advanced version of the present first year undergraduate course could be developed into a post graduate Masters course.

The elementary course described here consists of numerous components that lead the students towards basic competency in engineering design and innovation. Students work at the bench in a laboratory and strong emphasis is given to minimum lecturing time and maximum time given to a problem-based-learning hands-on approach to teaching.

The innovation side of the course is based on the students coming up with ingenious solutions to some of the problems. In fact innovation is based not only on the innate ability of a student but also on her/his engineering knowledge and experience in problem solving coupled with knowledge of manufacturing techniques. Hence one of the components of the course is concerned with using a manual lathe and milling machine. Both machines will be utilised in the second semester by student team members for the construction of their potato machines.

The specially designed English communication skills course underpins and supports the presentation and communication skills required for the Design and Innovation course. The methodology adopted is such that at specific times in the course, the content specialist, i.e. the engineer specialist, and the communication skills specialist, team-teach in the English class and this continues into formative evaluation such that the constructive feedback is both from the engineering angle as well as the communication skills angle. Students see the relevance and importance of both aspects of this course and realise the value of the skills they receive in the communication skills course because it enables them to be better prepared and more in tune with the ways of knowing and doing in their Engineering community. It is just as beneficial to the engineering lecturer because it allows him/her to concentrate on what he or she is good at and leaves the other aspects required by the engineering fraternity to be directly taught by the communication skills specialist. In the past these communication skills are traditionally learned on the job in industry on an ad hoc basis and this can impede second language learners from getting ahead because they have to contend with unfamiliar genres in a language that is not their mother tongue while grappling with the responsibilities of their new job. A symbiotic teaching partnership like ours gives students that much needed head start and we feel that the methodology that we are advocating may prove relevant even to students for whom English is their primary language. This is because knowing how to speak English does not necessarily equate with effective communication in the discipline-specific genres of the engineering community, (as the first author knows too well to his cost) The pedagogy outlined here would play a significant part in preparing Bruneian engineering students for employment in a global borderless market that is increasingly competitive and knowledge-based. A course such as this would ensure that there is a better correspondence between industry's demands for an educated workforce that is articulate. We can achieve this through the use of the current best engineering and English communication practices for providing the human capital necessary for nation building and sustenance.

II. COURSE PHILOSOPHY

The two courses attempt to impart to the student a portfolio of skills that provide a foundation for the skills of engineering fundamentals in design and innovation and the communication skills crucial for effective participation in the program. The portfolio is imparted by challenging the student to work on numerous engineering design sub-modules where each sub-module poses one or more design problems. However, the students study a number of possible solutions but finally pursue only one solution to one specific problem and when possible the students hand craft their solution in the form of an artefact, e.g. a cardboard model. The communication skills course runs parallel, carefully providing the scaffold required. The solution to a specific problem on hand is in direct contrast to a general solution to a generalised problem where many solutions are considered and only paper and/or simulated solutions are pursued. In the former the students are engaged on solving a specific problem for which there is no ready made solution or textbook lock-step-directed procedures. Students are given general solutions to general problems for which they have only superficial knowledge and to make things worse, have no workbench knowledge. More importantly, whether it is engineering fundamentals or English communication skills, the learning in this context is both for the teacher as well as the student. Both are finding ways to understand a problem by experiencing it at first hand and then to design, innovate and a manufacture a solution based on immediate assessment of student knowledge and the task at hand- thus modifying and adapting information and instructions to suit the cohort and the learning. When students are actively involved in solving a real problem that they have in hand, they get involved, committed and are genuinely engaged collectively to find ways to solve their problem. This would of course be in direct contrast to a problem that is a merely a tutorial exercise for which they do not see real life relevance but as course content that they must reluctantly complete.

Students can only understand and appreciate general solutions after they have understood specific solutions together with the personal hand crafting or construction of artefacts. Thus this course has a built in manufacturing learning component The primary goal of a design engineer is to design artefacts with stored intellectual expertise that has been created by that design engineer. It certainly is the first author's opinion that design engineers can only be effective at their discipline if they have adequate knowledge of manufacturing principles. This is important because the act of manufacturing a piece-part of a product or a complete product requires personal decision making and personal responsibility since errors cost time and money. Because of space constraints, the rest of this paper can only focus on the engineering strand of the course.

II. UNDERSTANDING THE PROBLEM TO BE SOLVED.

Repeatable quality is expected by all of us when we make purchases from high street shops whether it is clothes from MNG or shoes from Timberland or a new car from Toyota. The same is true for food processing factories that supply supermarkets, hotels, airlines, McDonalds, KFC and Pizza Hut. These consumer outlets all rely on high quality food production contract facilities that produce food components such as raw French fry chipped potatoes to a repeatable quality. Technology can be harnessed to enable the repeatable high quality of manufactured goods.

Students are asked to assume they are engineers working in the hotel and airline food processing business. High quality is required for food on airlines because accurate weight, accurate volume, low cost, good aesthetics and good taste are critical for aeroplane performance and passenger satisfaction. The same quality for food is required by hotels where customer satisfaction is the main requirement. One example of a high quality food product is the “Chateau” potato, figure 1, and an engineering drawing specification of the shape is shown in figure 2.

The Chateau shape is similar to an American football with eight curved sides but the shape can consist of any number of sides from three upwards. The formation of this shape is labour intensive, requiring teams of workers sitting for long hours manually shaping the vegetable using a knife. The shape is subject to significant geometrical variations and takes approximately 10 seconds to produce one Chateau potato. The specification of the potato machine is to produce a Chateau whose geometrical dimensions are much more accurate and that a Chateau potato is shaped in five seconds.

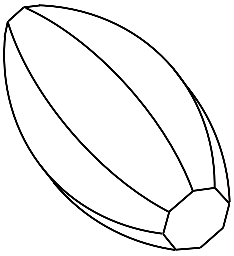


Fig. 1. (figure above) perspective view of Chateau potato

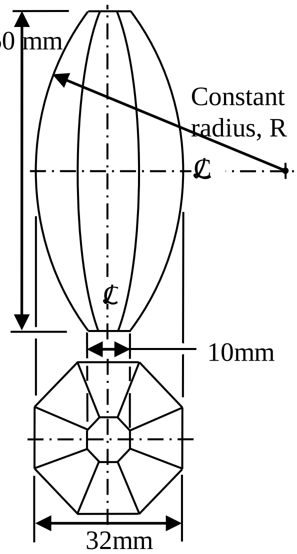


Fig. 2. (figure right) Geometric specification of the Chateau potato.

The students are not expected to construct a machine that produces a Chateau potato from a raw potato. Instead the potato will be pre-processed, figure 3, such that it is “topped and tailed” and then shaped into a cylinder of diameter 40mm and length 60mm. The potato is now ready for shaping into a Chateau potato.

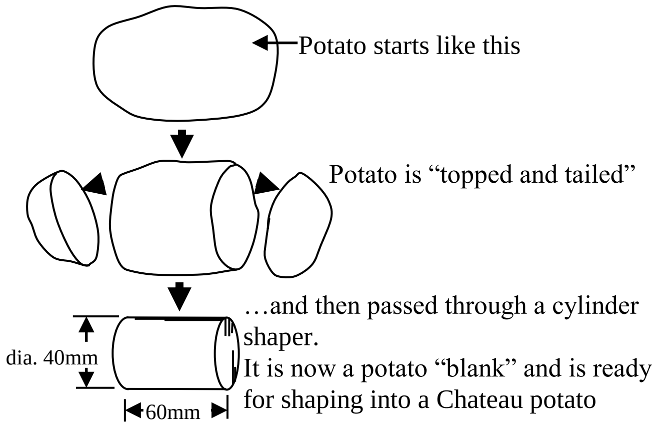


Figure 3. Pre-shaping the potato ready for processing by the Chateau potato shaping machine

Pre-processing the potato into a cylinder is the subject of another machine to be designed at another date. In the meantime, the students are expected to fashion the potato into a cylinder by hand and then to enter the cylinder into their machine for forming into the Chateau shape.

III. UNDERSTANDING MEASUREMENT ERRORS, ACCURACY, RESOLUTION AND SIGNIFICANT FIGURES

The students measure the density of potato substance by cutting a rectangular shaped block from a potato that is as square as possible as guessed by eye, figure 4. They then use a rule to measure the block dimensions as accurate as possible and then the block is weighed on a weighing scale which has one gramme measurement resolution. The block dimensions are used to calculate its volume.

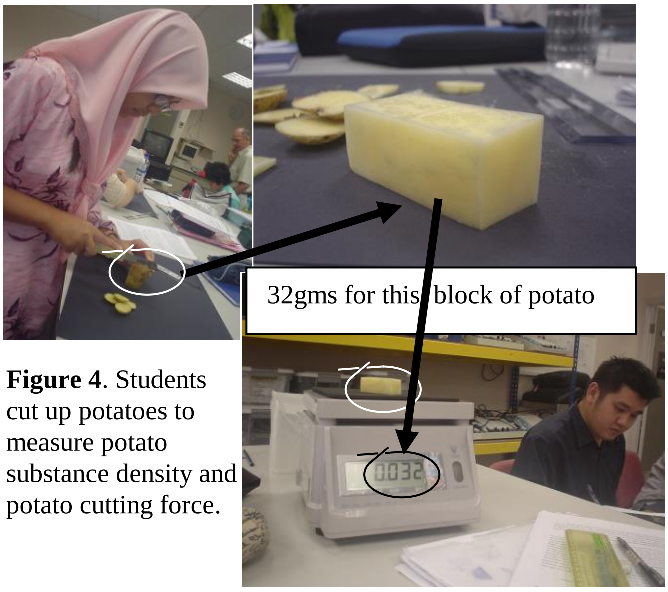
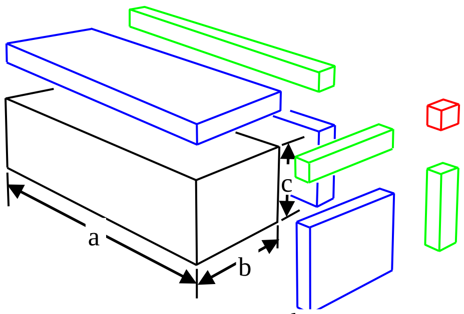


Figure 4. Students cut up potatoes to measure potato substance density and potato cutting force.

Due to the 1 gramme weighing scale resolution the weighing scale measurement error is approximately 0.5gramme. Added to this error is the volume measurement error. Students then proceed to estimate the density error ratio, figure 6.



$$\text{Density error ratio, } \frac{\rho_{error}}{\rho_{true}} = \pm\left(\frac{e_m}{m_{true}} + \frac{e_a}{a} + \frac{e_b}{b} + \frac{e_c}{c}\right)$$

Figure 6. Measuring the density of potato substance and the errors of its measurement.

e_m = mass measurement error; m_{true} = true mass

e_a = dimension error of a

e_b = dimension error of b

e_c = dimension error of c

The potato density measurement will be used later to estimate the weight of the Chateau potato; but first the students must calculate its volume as described in the next section.

IV. NUMERICAL ANALYSIS USING EXCEL SPREADSHEET

The volume of the Chateau potato can be calculated using integral calculus, which in this case, is not straightforward. So the students are asked to use Excel spreadsheet to divide up the shape into thin "sliced bread" strips, figure 7, and then sum the volume of all the slices. Interestingly this is the method used before Calculus was invented. Students also consider slices other than the strip shown in figure 7.

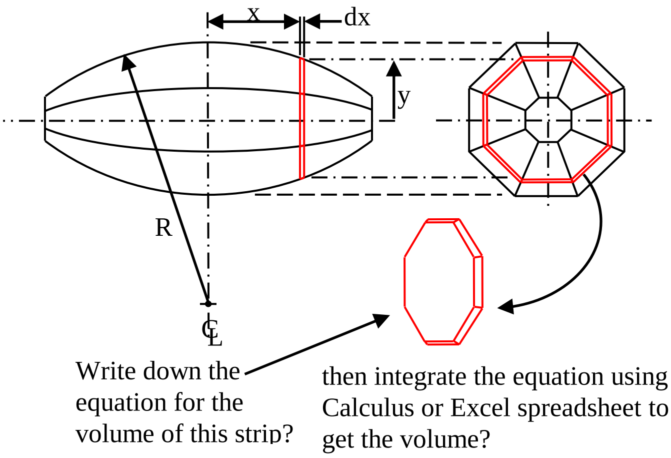


Figure 7. Volume of Chateau potato using "sliced bread" elemental strip.

V. USING ENGINEERING DRAWINGS AND CARDBOARD MODELS TO SOLVE AND VISUALISE ENGINEERING PROBLEMS

Engineering drawing and cardboard models can be used very effectively to visualise and solve many engineering problems, figure 8. It means that a calculator and/or computer are not used. Instead problems are solved with a mechanical pencil (0.5mm lead), A3 by 1mm grid graph paper, 360^0 protractor, rule and rubber eraser. Orthogonal projections (3rd angle) are used together with projections of true lines and true planes, figure 9, but little attention is paid to teaching drawing standards such as the correct way to dimension drawings.

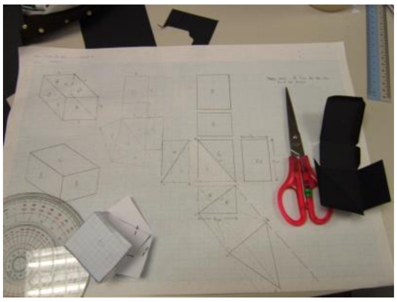


Figure 8. Using paper pencil, engineering drawings and cardboard models to visualise and solve engineering problems

Much more importantly the students are challenged to visualise 3d shapes in a number of 3d directions. As a result, engineering drawings can give solutions to problems as low as 1% error or even as low as 0.1% error which is adequate for many engineering problems. The making of cardboard models is a very effective visualisation method. For example, students are tasked with constructing cardboard boxes and pyramids, figures 9 to 12. These cardboard models when built enable the students to better appreciate engineering drawings that show 3d views.

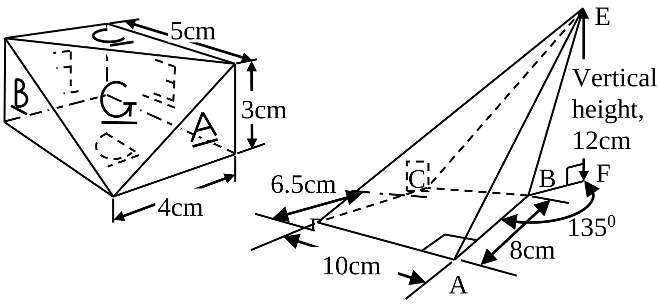


Figure 9. True line and true plane problems using a cut box and a pyramid

Figure 10 After making engineering drawings and working out true lines and true planes the students construct a cardboard model of the cut box

Students solve the pyramid problem then design and build one from cardboard, figure 11, figure 12 and figure 13.

Figure 11

Figure 13

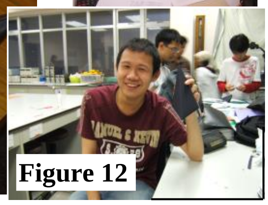


Figure 12

A more challenging design problem is now undertaken by the students. The problem is to design and build a three times full size cardboard model of the Chateau potato by students working individually. The Chateau potato, figure 1, consists of 10 pieces whose size and shape are shown in figure 14.

Figure 14. The 10 pieces of cardboard that produce the Chateau potato shape, (figure 1).

The Chateau potato model construction technique is studied and planned by the students. For example, what are the true views of the curved sides and how are the views calculated and how are the 10 pieces of cardboard joined together? Respective solutions include using engineering drawing/Excel spreadsheet and tabs/insertion tongues. Also there is a problem of securing the last piece in place which results in a different design for the penultimate piece, figures 15, 16 and 17.

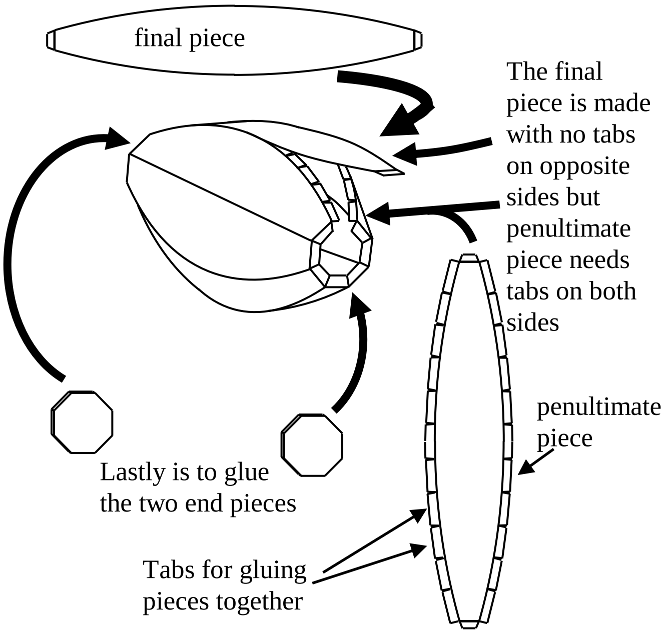


Figure 15. Construction of the cardboard potato

Figure 16. The last few pieces are a bit tricky to glue in place

Figure 17. 3-times full size cardboard models of the Chateau potato built by the students

The constructional accuracy of the Chateau potato models is checked by go-no-go gauges which check the accuracy at two perpendicular axes, figures 18 and 19.

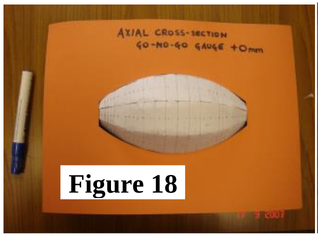


Figure 18

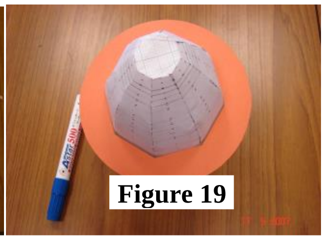


Figure 19

Using go-no-go gauges to check accuracy of the Chateau potato cardboard models in two perpendicular axes

VI. BASIC STRUCTURES

Many, if not most, of mechatronic products require a mechanical structure to either support the electro-computing system or to carry out a physical task or both. For many applications the mechanical structure must be stiff, strong and lightweight. Exceptions are mechanical springs which are deliberately designed to be compliant (not stiff) but nonetheless should be strong and lightweight in most cases. For a mechanical structure to be stiff, strong and lightweight, two properties of the structure are equally important. These two properties are: -

1. The mechanical properties of the material and,
2. The shape of the structure

The importance of the shape of the structure cannot be over emphasised. It is a core component of the design of mechanical components and systems. This course only spends a short time on the shape of structures due to its introductory nature. The shape of structures is such and important area of mechatronic product design that it is worthy of being an advanced course.

Two suitable materials that possess relatively good properties of materials meaning that they have high strength to weight ratio and high stiffness to weight ratio are balsa wood and cardboard. These materials are easily available, relatively inexpensive and easily shaped with either a pair of scissors or a knife. They are also easily fastened together with glue or sticky tape.

Two of the most common shapes that produce strong, stiff and lightweight structures are: -

1. the box beam made from sheet material, figure 20 and,
2. the box beam made from a triangulated structure, figure 21

A closed box that is fastened at all corners by glue or screws is stiff, strong and lightweight. It is stiff and strong in bending stiff and strong in compression as a strut and stiff and strong in tension as a tie and stiff and strong in torsion. The box can be triangulated or can have holes in it. The box can have a square cross-section as shown in the photo or the cross-section can have 3 sides or multi-sided so that it could be a circular tube. The box section can thus serve as a strong stiff lightweight structure for an aeroplane fuselage or as a body for an automobile. Closed boxes need not be of constant cross section. So long as they are fastened at all corners then they will be stiff strong and lightweight.

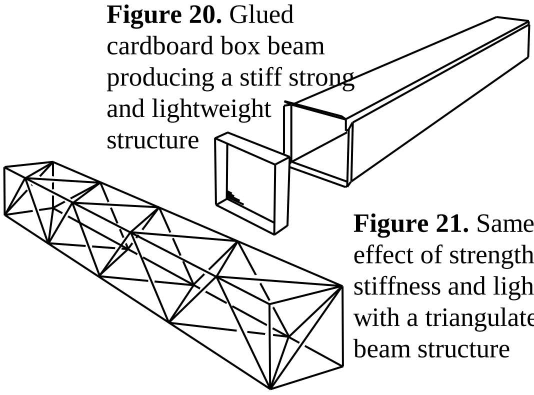


Figure 20. Glued cardboard box beam producing a stiff strong and lightweight structure

Figure 21. Same effect of strength, stiffness and lightness with a triangulated box beam structure

Students now set to work and create their own box beam from sheet cardboard, figure 22.

Figure 22. Student holding a stiff strong lightweight box beam made from cardboard that he has just built

Armed with this knowledge of how to create strong, stiff and lightweight structures, the students are challenged with designing and building a bridge structure that will support a 1kg load at its mid span. The specification is shown in figure 23.

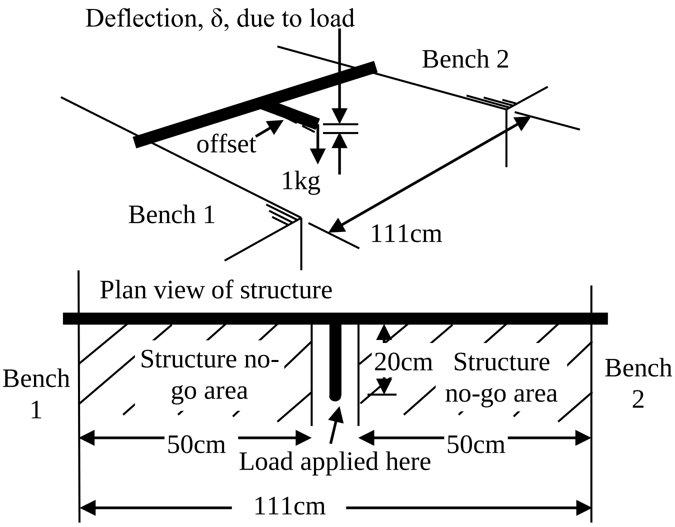


Figure 23. Specification of bridge structure to be built by students working in groups not exceeding 3 students

The structures are judged on the stiffness-to-weight ratio (lowest value of structure mass, m x deflection of the load, δ) and the structure must not collapse under the weight of the load. Students may use steel for their structure but they are reminded that steel is much denser than balsa wood or cardboard. Figure 24 shows a bridge being weighed and figure 25 shows the deflection being measured.

Figure 24 Bridge structure under test for its mass measurement

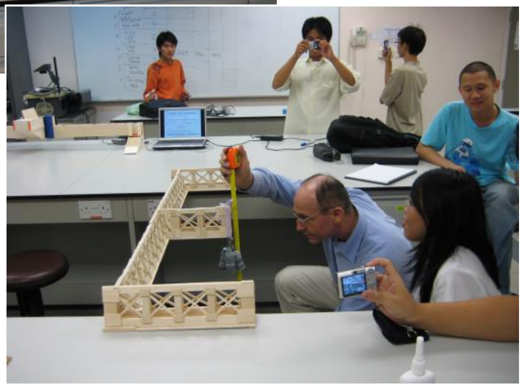


Figure 25 Bridge under test for its deflection under a 1kg load.

VII. WORK IN PROGRESS AND FUTURE WORK

This paper describes the course progress for the first 12 weeks of the 28 week course. The students are currently working on a mechatronic machine design for shaping of Chateau potato. They have already given presentations on their designs and feedback will be given next week. The Basic Stamp microcontroller was introduced recently in week 11 as a device that can be used to control their machine. They will spend 3 more weeks learning more about this microcontroller and this will bring them to the end of the first semester. At the beginning of next semester, week 15, the students will be introduced to basic workmanship on a manual milling machine and manual lathe to enable them to manufacture their own components. At week 18 they will start constructing a mechatronic Chateau potato shaping machine of their own design which is to be finished and be able to shape potatoes by week 27. They will then give a presentation and formal report on their machines at week 28. A further paper will be written to describe the events following on from this paper.

Francis Nickols is an Associate Professor at the Engineering Science Department in the University of Brunei Darussalam. He has designed and built numerous products that include electromagnetic flowmeters, intelligent machine tools and walking robots. His research interests lie in mechatronic engineering, autonomous mobile robots, computational intelligence and engineering innovation and design.

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