First Year Structures Teaching – Changing Demands

Introduction

The basics of structural mechanics are essential to all progress in structural engineering at degree level and later in professional practice. Given this, there has been surprisingly little change in how structural mechanics is taught in at least fifty years – a traditional lecture-tutorial model still dominates in most universities, and many key texts have been published in multiple editions after originating in the 1950s. This stasis is in the face of substantial changes in technology, pedagogy, and the student body over the last twenty years, which all point to possibilities for new and more effective ways of teaching structural analysis. In 2014 to take advantage of these possibilities, "Structures 1", the introductory structural analysis course delivered at the University of Manchester, was completely redeveloped. The high-level pedagogic aim was to produce a course that responded to recent changes in higher education and technology, and which emphasised the likely skills required by future graduates. This article describes the rationale, content and effectiveness of this work.

Rationale and Approach

With the high-level pedagogic aim in mind, Structures 1 was re-developed taking account of the following considerations

1. The Structures 1 class is highly varied, both in terms of student background (40% are international students) and subject (it combines aerospace and civil engineering students). This means there is a large range of learning styles, interests and abilities. To teach such a varied class effectively requires learning material to be similarly varied, so students can adopt a learning style that is most effective for them. A restricted lecture-tutorial model would not be optimal.
2. Structural engineering (and other disciplines) are changing as computers undertake a significant and growing proportion of work. The rate of change is increasing so undergraduate engineers need an education that is future-proof against automation of, for example, aspects of structural design. A greater emphasis than previously on conceptual understanding of structures (with perhaps less focus on great ability at complex hand-calculations), creativity, and ability at handling unfamiliar problems is needed to fulfil this need.
3. Structures 1 is a large class with around 220 students. It is impossible for a single academic to spend significant time with each student individually in a class of this size, yet such "social" teaching enhances understanding and engagement greatly. Moreover, one-to-one interactions are invaluable for helping academics understand where common misconceptions lie. Novel teaching methods and use of technology offer means of squaring this circle.
4. Structural mechanics requires students to grasp a number of "threshold concepts". These are ideas that are difficult to "get", essential to progress in a subject, but, once mastered, not easily forgotten. In Structures 1 they include topics such as equilibrium, bending moments, and structural stiffness. Traditional lectures and written notes are a relatively poor way of teaching threshold concepts. Lectures are transitory, so, if a concept is not immediately grasped when presented, the chance to do so is lost. Notes and books tend to have extensive detail that can obscure key concepts. Imaginative methods of teaching and methods of allowing students to ensure they have grasped threshold concepts are desirable.

Taken together these considerations pointed towards a multi-faceted, "blended-learning" approach which whole-heartedly embraced e-learning and other technological developments, while still maintaining traditional aspects such as lectures and tutorials. Therefore, a wide range of interlinked material was developed including; key-concept videos, discussion boards, online quizzes, and practice software, as well as lectures, notes and tutorials (details below). This approach had the advantages of offering students a variety of forms of learning material, much of it available at any time or any location; of allowing individual and one-to-many communication with and between students; and of allowing a shift in emphasis to conceptual understanding.

Conversely there was a danger that with such a wide-range of material the course could become confusing and feel incoherent to students. This was countered by providing a "map" though the content (Figure 1) and careful signposting and arrangement of the course material on Blackboard (a virtual learning environment).

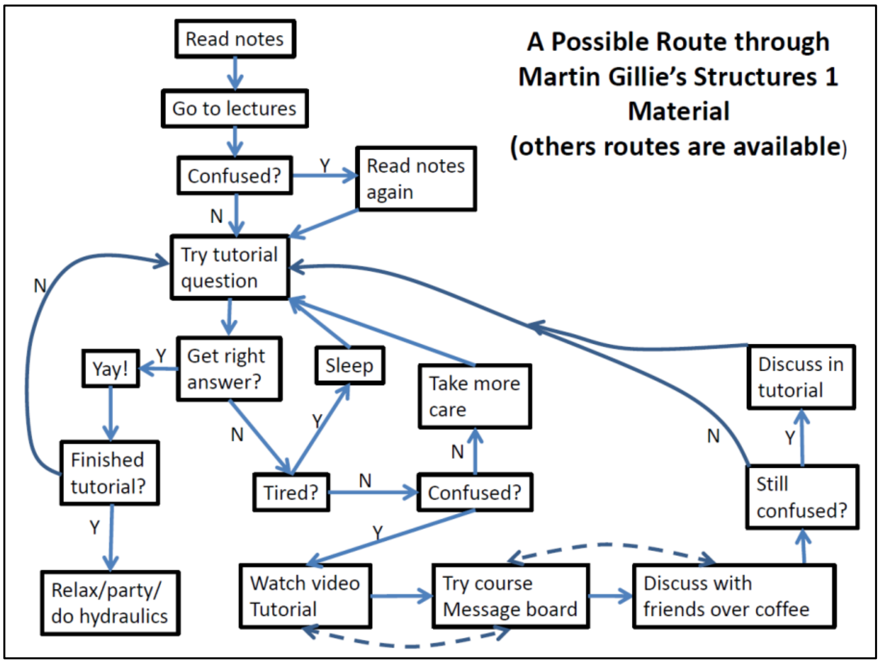

Figure 1 A "map" to guide students in using a varied set of learning material.

A Blended Learning Approach – the Components

Below, the various components of the re-developed course are presented in detail with the aims and implications of each component discussed.

Key Concept Videos

Videos of about 5 minutes in length were provided for the key ideas and threshold concepts in the course. These focussed on conceptual understanding rather than details of calculation methods. The aim was to enhance students' understanding of fundamentals in ways beneficial for interpreting computer output, critiquing structural designs, and other such activities which are increasingly important in later undergraduate courses and practice.

These videos were developed as handwritten, digital whiteboard style presentations and produced on an iPad. This allowed concepts to be introduced incrementally with a voice-over describing ideas as they were developed using diagrams and simple algebra. The videos are short (<5 minutes) and focus on a single concept. Considerable thought was given to presenting the ideas in as clean and clear a manner as possible and several iterations were generally needed to get a video right. Students thus had readily available descriptions of the most important ideas available in a distilled form that they could access anywhere, at any time and on any tablet, phone or computer.

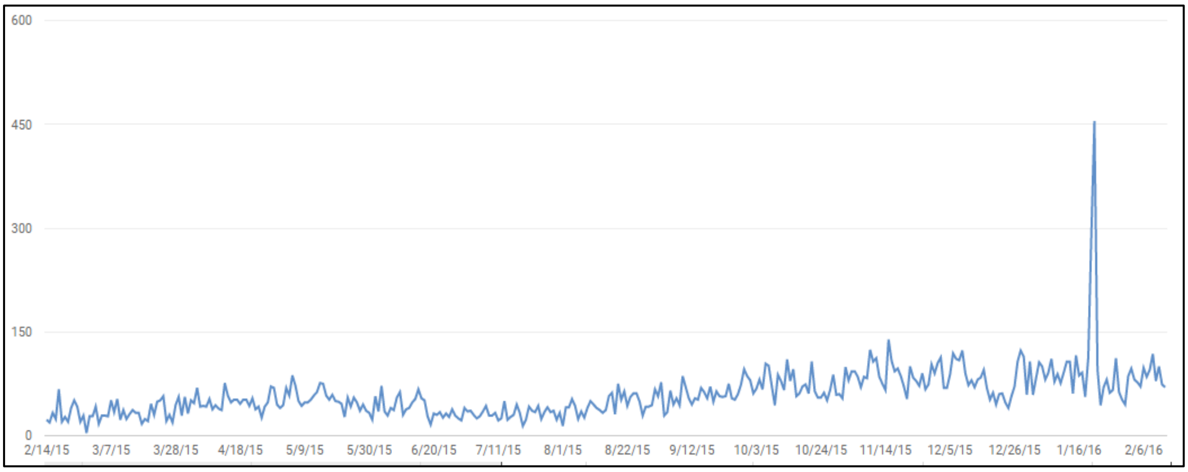

Figure 2 YouTube analytics data showing number of views by date for all Structures 1 key-concept videos. The spike occurred in the days immediately prior to the exam.

By hosting the videos on YouTube and embedding them in Blackboard, it was possible to make the videos readily available and also to collect fine-grained usage data via YouTube Analytics. The implications of this data were sometimes obvious as in Figure 2. There are also deeper trends which were studied during a project evaluating student use of "rich-media" resources (below).

An unanticipated benefit of hosting videos on YouTube was the wider audience this attracted. Currently the videos have been viewed over 25,000 times (around 2000 views a month) and the YouTube channel has 650 followers. Around 50% of these views are from outside the Structures 1 cohort, engaging potential structural engineers globally. Although there are currently no plans to extend Structures 1 to a MOOC (massive, open, online course) model, these numbers suggest the potential for a structural engineering MOOC does exist.

Quizzes

Quizzes have a long history in education but new opportunities have been opened by electronic platforms. Firstly, an electronic based quiz system is much more powerful than a paper based one because it allows questions to be selected flexibly. For example, questions can be automatically grouped by topic, or arranged in increasing order of difficulty, or selected based on participants' answers to previous questions. This allows for a much more focussed and targeted use of quizzes than paper-based systems. Secondly, by collecting data on students' answers, it is possible to pin-point topics and concepts that are proving troublesome, allowing academics to clarify these points. Finally, by introducing an element of competition, it is possible to "gamify" learning in a way that encourages participation and engagement.

In Structures 1 these advantages were exploited by developing quiz questions in Blackboard. As with the key-concept videos, the questions (e.g. Figure 3) were mostly designed to test conceptual understanding rather than ability at detailed calculations. This meant questions could be answered quickly in multiple-choice format and statistical data on student responses could be collected. Students were given feedback on each question outlining the reasoning that led to correct answers and highlighting common misconceptions. By examining the statistical data, it was possible to improve this feedback in the light of previous answers – for example, if a certain misunderstanding was common, a more detailed explanation of why could be added to the feedback.

Initially questions were presented in groups of about ten, with each group focussing on a topic such as truss analysis, or bending moment diagrams. The highest score obtained within a week for each group of questions was awarded a prize, so, while no marks were at stake (and there was thus no fear of failure), there was an incentive for students to take part and engage early with the course material. Later, all questions were made freely available for revision, with a facility for students to select by topic or difficulty.

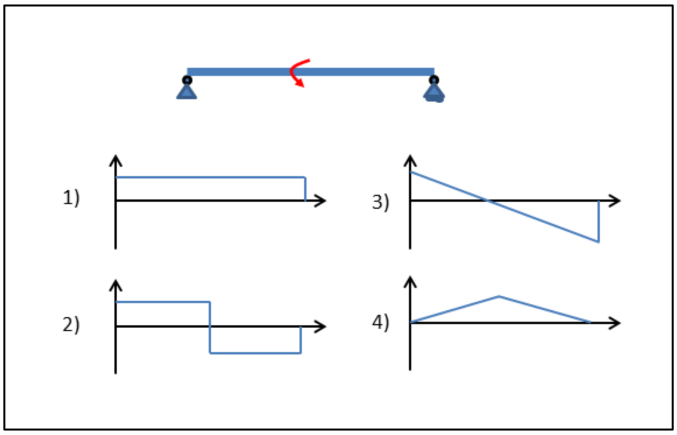

Figure 3 A typical quiz question, in this case testing understanding of the shear force distribution in a beam with a point moment applied.

Online Discussion

Individual communication between lecturers and students in large classes is challenging because of the limited time available for face-to-face interaction. There are further difficulties if there is a common misconception among students many of whom then email the lecturer. Responding in a similar manner to such emails is time consuming and inefficient, yet expecting students to wait until the next timetabled class for an explanation unreasonable.

These difficulties were addressed by providing a web-based discussion board in Structures 1. This allows many of the advantages of individual interactions to be present even with very large classes. For example, a discussion board allows the lecturer to reply to students' queries rapidly and outside scheduled classes in a manner that can be accessed by all students, reducing the need for multiple, similar explanations. Yet, by careful attention to the tone of replies, a degree social rapport is developed, even when replies are relevant to many students. The discussion board also allows students to post questions anonymously. This is a substantial advantage for students who are reluctant to ask questions freely in public, as is often the case in a large class and particularly so for students from certain cultures. A final benefit of a discussion board is that it allows students to respond to each other, sometimes by answering questions and sometimes by developing questions further, or querying a subtlety.

Practice Software

Calculating support reactions of beams, and determining shear and bending moment diagrams are key topics Structures 1. These are also topics that are challenging on first acquaintance and require considerable practice to master. The traditional approach is to provide students with questions on a tutorial sheet containing maybe a dozen questions, normally of increasing difficulty. To access further questions students must acquire a text book. While somewhat effective, this approach has limitations: the nature and level of the questions follows what the author of the questions thinks most helpful rather than what the student most needs (which will be different for every student); the bank of questions is quickly exhausted; and text books are expensive and heavy.

To bypass these shortcomings, a dedicated piece of software was developed for Structures 1 that produced beam analysis questions at a level controllable by the user. The interface is shown in Figure 4. The user controls the type (and effectively difficulty) of question by selecting the types of load to be applied to a simply-supported beam. The software then generates a question including these types of load applied randomly, allowing an essentially infinite number of problems to be produced. To obtain the support reactions the users clicks a button, to see the shear force diagram a second button, and to see the bending moment diagram a third button. The software can be used either to practice quantitative analysis of beams or to check ability at sketching shear and bending moment diagrams qualitatively. It was made available to students in the university computing laboratories and the Matlab code was also made publically available so students could install (and extend) the software on their own computers.

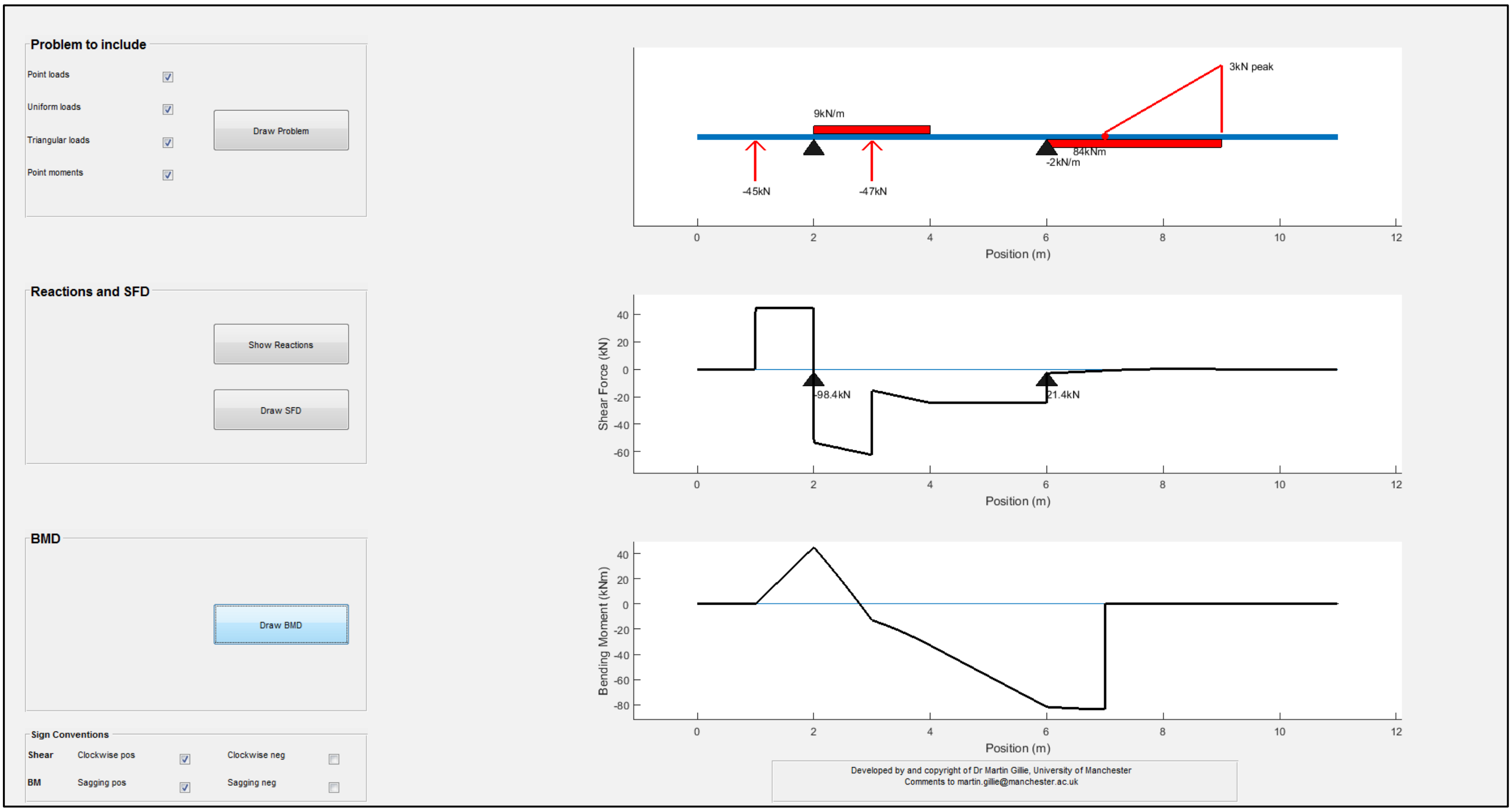

Figure 4 Screen-shot of the software developed for practicing calculating reaction forces, shear force diagrams and bending moment diagrams.

Lectures, Notes and Tutorials

Despite the limitations in a solely lecture-notes-tutorial model of teaching noted above, these aspects of the course were maintained because, if present with the novel aspects described, they still have considerable merit.

Completely new notes were developed for Structures 1. These covered the syllabus in detail and presented calculation methods, together with example problems. The notes were provided in paper and also electronic form so links could be included to other material, creating a tightly-bound, cohesive course. The notes were supported by tutorial questions and associated classes. In the tutorial classes, one-to-one discussion was possible between students, and the lecturer and tutors. Postgraduates and later year undergraduates were used as tutors. The undergraduate tutors were selected on ability with the intention of providing high quality tuition to the class, and also the tutors with opportunities to gain greater insight into the course material, and practice at technical communication.

With both the detail and concepts well-covered by other material, the focus in lectures was on the context, challenge and power of structural analysis. Generally detailed calculations were avoided, although example problems to indicate the scope, and limitations of methods were presented.

Considerable use was made of videos and other engaging material to ensure interest. The University of Manchester automatically records all lectures so that students can view them at any time after delivery.

Assessment

Traditionally, assessment on basic structural analysis courses emphasises ability at solving some fairly standard problems – bending moment distributions, truss analysis, deflections calculations etc. – using an algebraic approach. Typically a two to three hour exam is used comprising questions taking about thirty minutes each. There is no doubt ability at such calculations is required by engineers and assessment of this type is needed. However, used in isolation, it has flaws. Solutions to traditional questions involve substantial amounts of fairly low-level algebraic manipulation, which takes a lot of time. By contrast the intellectual input is limited – normally to identifying the problem type and a few other key points - and takes little time (Figure 5). Thus traditional exams disproportionally test algebraic ability with proportionally little probing of conceptual understanding of structures, a situation of questionable merit.

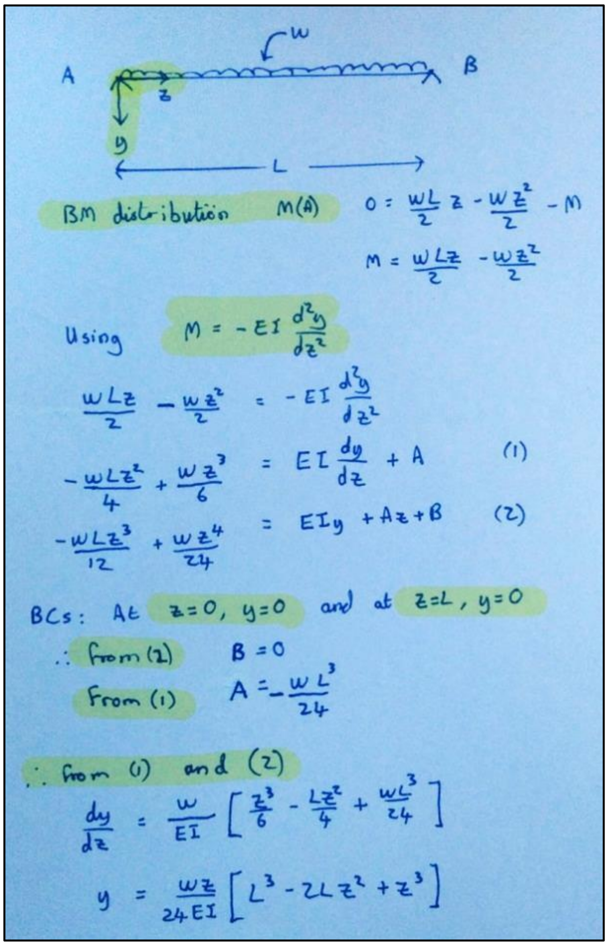

Figure 5 The solution to a typical traditional exam question. The parts requiring knowledge beyond basic algebra are highlighted; they amount to less than one third of the solution. In a typical exam script errors and less compact presentation would result an even lower proportion.

In line with the course rationale, Structures 1 assessment was adjusted so the balance moved towards testing conceptual knowledge. This was done in two ways. Firstly, a multiple-choice element was introduced to the exam consisting of ten questions, each taking nominally three minutes. Twenty-five percent of the marks were awarded for these questions, each of which required conceptual knowledge of structures but no algebraic manipulation and were similar to the quiz questions (Figure 3). This meant assessment of conceptual knowledge was expanded to three times that in the previous exam format, while assessment of ability at algebraic style questions remained at seventy-five percent of the previous level.

Secondly, an open-ended coursework element was introduced to the course. Students were asked to "identify study and research the behaviour and design of an existing structure", and report the findings as they chose. Group work, choosing an unusual structure, and creativity in presentation were all encouraged. The idea was to emphasise that structural engineering is about more than calculations, with interpreting structures, critiquing design and communicating structural ideas all being important. These aims have been embraced by students who over two years have submitted some remarkable work, including an analysis of the structural mechanics of their lecturer, presented as a video!

Evaluation

The course has now been delivered twice and evaluated twice by students via end of course questionnaires. The ratings were exceptionally high (the highest of any civil, aerospace or mechanical engineering course delivered at Manchester University in semester 1 2015/16). This is in marked contrast to the ratings prior to the redevelopment, which were mediocre at best. These ratings have been supported by numerous positive written comments about the course by students, many noting the benefits of the blended-learning approach. The expectations and desires of students have clearly been met.

To understand in more detail how students used the video resources available for the course (key-concept videos and lecture capture), a research project examined analytics data, survey responses and focus group discussions. A key finding was that video resources are highly valued by students generally and particularly by certain groups, such as those with English as a second language. Generally short, focussed videos were preferred to longer lecture capture material. It was also found that having video resources available only had a marginal effect on lecture attendance overall, and for some students the effect was positive. This is in contrast to some findings and the reasons cited by some academics for not providing video resources. More details of this study are available here.

Conclusions

The complete re-development of a structural mechanics course was an opportunity to respond fully to changing teaching and structural engineering settings. The limitations and shortcomings of a traditional teaching model were addressed but the strengths of that model were maintained. This resulted in a course that allowed students to learn in places and ways of their choosing but maintained the advantages of personal interaction and social learning. The course thus exploits the university environment and avoids the impersonality of a complete distance learning approach. Students responded very positively to this approach with both online and direct teaching material being favourably received, and the course exams results being high. A fully-blended approach is a highly effective way to teach modern, large, varied classes and to provide an education in conceptual understanding of structures and ability to calculate detailed results.