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Learning advanced engineering online: from distance delivery to online learning of finite element analysis

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Abstract

This paper reviews Open University distance learning of finite element analysis (FEA) in MEng degree qualifications recognised for Chartered status. Presentation has evolved from physical study packs to fully online. The emphasis is on understanding limits and assumptions behind all aspects of FEA for safe and effective use. Guided exercises bring out modelling and analysis issues in real systems. Case studies of a Formula 1 racing car focus on a stepped approach illustrating the FEA process. The paper outlines the assessment processes and teaching philosophies, expected outcomes, marking, handling and processing of students' final results. The paper gives observations of many years of presenting education modules in FEA for study at a distance. It gives recommendations for module design, content and styles of presentation, and an evaluation of online study compared with traditional methods. Challenges include providing text, video sequences and complicated mathematics in online form for use on different access devices.

1.0 Background – origins

The Open University (OU) was established by Royal Charter in 1969 as the UK's only University dedicated to distance learning. It is open in terms of providing educational opportunities to all who wish to realise their ambitions and fulfil their potential. It focuses on the design and delivery of supported distance learning programmes, either for single modules or full profiles for recognised degree qualifications, both undergraduate and Post-graduate. At any one time there are more than 200 000 active students and the University consistently ranks at or near the top in national student surveys for overall student satisfaction. The Open University also has a research profile which ranks consistently in the top third of UK higher education institutions.

Many OU modules are available throughout Europe and worldwide, either directly or through partnerships and accredited institutions, and since 1969 over 2 million students have achieved their learning goals. People of all ages and backgrounds become students for all sorts of reasons but over 70% are working either full or part-time during their studies.

The teaching materials themselves originally comprised specially written and printed hard copy booklets, occasional face-to-face tutorials, associated TV and radio programmes broadcast on the BBC national networks. The latter moved on to VHS and audio-cassette tapes, then DVD presentation format. In the last twelve years however, most teaching has moved online as computers connected to the internet have become the norm and broadband connections have improved.

2.0 Development of FEA modules, concerns and initial ideas

The Open University involvement in the field of FEA can be traced back many years following concerns that computing hardware and software were developing at a rate faster than the qualifying skills and knowledge to use them effectively. Increasing accessibility and cheapness of commercially available analysis packages, combined with the sophistication of pre and post-processing systems, could obscure bad design and judgements. Engineers (and non-engineers) with little knowledge of the basis of the method could use it unaware of the dangers of for example (a) creating a poor model; (b) using an analysis code with inappropriate elements; (c) assuming incorrect boundary conditions or support restraints; and/or (d) accepting beautifully produced plots of smoothed out results which were in fact seriously in error.

Contact was made with the then newly set up Glasgow-based National Agency for Finite Element Methods and Standards (NAFEMS) and in June 1986 the founding Chief Executive visited the OU to discuss and share concerns over these issues. It was agreed that there was scope for open access distance learning courses to bridge the gap between full time university-based academic study and vendor-based training offerings of particular computer packages. The FEA method itself as taught at university level is intensely mathematical and theoretical. It requires at least a full understanding of the mathematical theory (and assumptions behind it) of the analysis models, material properties, surrounding boundary conditions, etc. This would be under the aegis of 'education'. Training on the other hand involves the teaching of the skills necessary to use an FEA computer aided package. A vendor of such packages could not be expected in their user training to cover the whole background education needed for users to fully appreciate and use FEA tools authoritatively. It is the job of educators to do this.

A key catalyst event was the First International Conference on Education and Training in Finite Element Analysis held at Glasgow in September 1991, as reported by Boyle et al. (1991). The general theme of this conference was to:

...ensure that there are the users who understand the processes, can safely drive the software tools and also have engineering judgement to assess the validity of the results. Educationalists and trainers alike must ...ensure a balance between core knowledge and user understanding of the techniques being employed.

At this conference, and immediately following, colleagues teamed up with others from the University College Swansea and Rockfield Software Ltd. who all shared similar concerns. A proposed project was

formulated to develop a 15 point (roughly equivalent to 150 study hours) postgraduate level distance learning course on the safe use of the Finite Element Method in engineering. The format and content were selected following detailed market research and the course market was perceived to be practising engineers, high-level management in engineering organisations and higher education students.

The primary objective was to produce an introduction to the mathematical and engineering core of the finite element method, as well as to its practical application in a variety of different engineering disciplines. *It would also emphasise the need for thorough engineering understanding and appreciation of the assumptions, approximations and other limitations involved at all stages of the process.*

After many months of discussion, a group of European parties had been assembled as interested and collaborating partners, the project concept was finalised and start-up costs funded by the (then) Commission of the European Communities Task Force Human Resources, Education, Training and Youth COMETT programme. The main contributing partners were:

Rockfield Software Ltd (RSL), Swansea, UK

The Open University, Faculty of Technology, Milton Keynes, UK

Universidade Do Porto, Department of Civil Engineering, Portugal

LOLA Cars Ltd., Huntingdon, UK.

The educational materials themselves were prepared mainly throughout 1994 and 1995 as a standalone distance learning pack known as T525 – Finite Element Analysis. As usual for distance learning education materials at the time, each student would receive a physical pack of study materials in a quality presentation case (Figure 1). This comprised a variety of media including interactive computer-aided learning programmes, sample commercial F.E. code, video case studies, a standard textbook, various other printed materials including books and leaflets from NAFEMS. A comprehensive study guide directed students through the study materials in an orderly fashion.

Exercises, examples and self-assessment questions were also included but there was no formal assessment. Thus the course could be studied at any time and was not ‘presented’ in a formal manner. Full details of the development and content of this course have been published (Martin 1995; Martin and Matela 1997a, 1997b). The course was launched in 1996 and sold worldwide until discontinued in 2003. This was due to falling sales, the dating of some of the content and presentation methods (such as VHS tapes and floppy discs). It was also decided to expand the teaching presence in the field with a more extensive course that would be fully assessed and be an integral part of a recognised degree profile in engineering.

3.0 Development of full Post-graduate level module

Following experience with T525, it was proposed to extend the coverage of FEA education as part of the OU mainstream engineering portfolio. A module (“module” had by now replaced the term “course”) was envisaged at Post-graduate level in consideration of the engineering knowledge and skills needed prior to study of the subject. The proposed aims were:

to introduce the computational modelling and analysis techniques as used in engineering today
to instil the need for comprehensive evaluation and checking when interpreting results of computer modelling and analysis.

Figure 1. The first OU distance learning pack for education in FEA.

After a long period of discussion and development the module was produced and entitled 'T884 An Introduction to Finite Element Analysis.' It was postgraduate, 30 points (equivalent to 300 study hours) and divided into 3 main study blocks. It formed an essential part of the MEng. qualification and was a core component of engineering degree profiles for students aiming for chartered engineer status. T884 was launched in the spring of 2006 and continued in its original form with annual presentation to 2013. It was formally presented within a strict timetable of study, in distance learning format with tutor support and with assessment.

The structure of the course in terms of distance teaching of the subject has been reported by Martin and Matela (2002). In line with most of the university offerings each block of study material lists the aims and objectives of that particular study. Learning outcomes and assessment components are addressed to these. For example the aims of a study guide for Block 1 state:

1. to present the basic theory of finite element analysis;
2. to introduce the general procedures that are necessary to carry out an analysis;
3. to present the basic information that is necessary for the safe use of FEA;
4. to introduce the ANSYS FEA system.

A list of objectives (in this case 17) is given at the end of the study guide each one of which is linked to an exercise that the student will have attempted during study. By this means the student should have a clear understanding of what has been or is to be learnt from the study experience.

Learning resources included a set text book which covered most of the mathematical background theory, proprietary Finite Element Analysis software (restricted to an educational version with element number limit), printed guides, booklets and teaching texts from NAFEMS, specially written comprehensive study guides, and a newly produced DVD of case studies. The DVD included complete new case studies written and filmed with the cooperation of the Red Bull F1 racing team. It included 2 major design cases and a host of revision and briefing subsections. Figure 2 shows the Red Bull F1 chassis used as one of the case studies.

As with T525, a printed study guide drew on all the materials, steering students in a coordinated manner. The use of a textbook was intended to save time and cost during production. The aim was for the study guide to direct the student to draw on various aspects of the theory as covered in the textbook and then direct them to specific exercises to reinforce or test their understanding. It was thought that if the theory was already in published form then we should not need to write it out again – thus saving the complexity and costs of writing, processing and publishing mathematical texts.

Figure 2. The F1 chassis tub case study

Comments however from the support tutors and student feedback forms showed that the use of the textbook in this way was not popular with the students. Our students were used to and preferred the special style of writing for distance learning presentation. This is more lengthy than a textbook as it directs the student in an orderly way through the material.

Bearing in mind the student sitting alone at home with no classroom interaction for support, the writing has to be more of a logical progression and of a leading 'hand holding' nature avoiding gaps, non-

sequiturs and ‘thought jumps’ from authors. For example, a block of teaching material that might be appropriate for a text book could be 30 000 words long. When written for distance learning presentation this would be expanded to something like 100,000 words. The key feature is that the writing is in itself a teaching medium over and above that in text book or Powerpoint presentations which are essentially aids to the teaching environment.

The module still comprised a physical pack of materials as depicted in Figure 3, but note that the container had now been reduced in status to a cardboard box!

As T884 was now a mainstream module, students would be allocated an Associate Lecturer (AL, formerly known as a Tutor) for support. ALs form a vital part of the supported distance learning approach. They prepare and present their own online tutorials, offer general support and, importantly, mark and provide detailed feedback to each student on their submitted Tutor Marked Assignments (TMAs). Tutor guidance notes and sample answers are however provided by the module team. Other forms of assessment include the computer marked assignments (CMAs) which each comprise a number of key questions with multiple-choice answers or responses, only one of which is correct. Brief feedback is given with the correct answer after a cut-off deadline date.

Student assessment for T884 was by 4 CMAs and 4 TMAs of which the last 2 were amalgamated to form a final examinable project or end of module assessment (EMA). This required the submission of printed copies of a comprehensive report. The first 2 TMAs were submitted electronically. To achieve a pass credit, a minimum of 40% was needed in each component (i.e. continuous and final assessments). An outline of the module content is given in Appendix 1.

Figure 3. The second OU distance learning pack for education in FEA.

3.1 The End of Module Assessment

The EMA is the final examinable part of the overall assessment. It is a simulated engineering project for which each student has to carry out a finite element analysis on a single machine component. The analyses usually involve stress and deflections, vibration modes and (sometimes) a temperature distribution. This means students have to bring to bear many of the lessons and issues studied throughout the module, including those in the study block materials, the software exercises and case studies.

Although the component itself should be relatively easy to model, when it comes to meshing, applying the loads, deciding on boundary conditions, restraints, etc., it is anything but simple. As is often the case, there is no 'right answer' – students have to use new found analysis skills in making engineering judgments when tackling the analysis. Importantly, students have to write up the project in a comprehensive report so as to demonstrate these skills.

The report should cover details of all the assumptions, modelling strategy, verification trials and details of validation processes etc. Students are advised to conduct many analyses, fine-tuning to provide valid modelling of important details, such as any stress raisers, until satisfied that the results are meaningful. Reports should include at least the following:

- a clear statement of the problem and approaches to it;
- what mesh elements were chosen and why;
- what boundary conditions were considered and decided upon, including how loads are applied and the representation of any restraints;
- whether or not any symmetry or anti-symmetry conditions were applicable, and if so what additional boundary conditions were specified for these;
- what mathematical or other theoretical calculations were employed to validate the results;
- an appraisal of and comments on the results themselves in terms of the operation of the machine.

Thus the examiners are looking for understanding of the finite element analysis process. Students need to show that they are able to use it with safety and confidence, and identify and justify assumptions and decisions made in modelling, both implicit and explicit. This philosophy was behind all versions of the module from T525, through T884 and now to the online version, T804.

With regard to marking the EMA reports a guide sheet was/is filled in by the markers for each student. Appendix 2 shows a blank copy. This was used to allocate marks with specific reference to the above points and how well or if the student had addressed them. It also had a section for summary commentary. It was not meant as a teaching feedback mechanism to students but was used within the module team to quantify marking and as an 'aide memoir' in review discussions at award board meetings. (Teaching feedback had already been presented to students with the TMAs and CMAs).

4.0 Development of online FEA module

Although care had been taken not to 'time stamp' the study materials, inevitably both the content and means of delivery were aging towards the end of presentation of T884. There were also costs

associated with the supported presentation. On the plus side the module had been generally well received by students and some excellent EMA reports had been submitted over the years. After five years in production, a comprehensive internal review of the module was carried out. Issues addressed were assessment and marking, student numbers and performance, presentation costs, student retention, integration with undergraduate engineering programmes, student workloads and feedback from students, tutors and external examiners.

At the time of review, on average the module attracted 29 students per year, with 21 completing of whom 19 achieved a full credit pass. Average drop-out rates were thus nearly 28% and indications from the ALs was that most drop outs occurred quite early in the study schedule. Of students completing, over 90% achieved a pass/credit. Many of the points raised in the review were of a detailed internal nature but some general suggestions were made, including:

- present everything online, no paper
- remove the text book and replace theory with specially written material in OU style
- align assessment levels and numbers of questions with other Post-graduate modules
- ensure pre-requisite modules include mechanics, dynamics and vibrations to degree level, and some matrix methods of analysis
- add some FE formulation in undergraduate maths modules; something at level 3 introducing FEA would help
- provide bridging modules to top up deficiencies.

Not all of these were in the remit of the module team or could be addressed in the near future.

Although part of qualifications profiles, individual modules still had to be open access. Thus prerequisite studies in mathematics and matrix analysis, mechanics and materials were strongly recommended, and prior knowledge tests encouraged, but they could not be insisted upon or made compulsory, other than as recommended pathways for students following qualifications routes. It was still possible to study the module individually, not as part of a qualification.

It was considered by the module team that in general the structure and content of T884 had served the students well and that much of it could be retained or adapted in an updated version. It was decided therefore to maintain the 30-point postgraduate module on FEA but with five major changes in approach which were:

- move to fully online presentation for all aspects of the module;
- write all aspects of the mathematics and theory previously addressed using the set text book;
- include basic revision of materials science, dynamics and matrix methods of analysis;
- reduce continuous assessment components (i.e. CMAs and TMAs) to be in line with other Post-graduate modules;
- retain as much teaching material from T884 as possible.

The new module was coded T804. To harmonise policy with that of other postgraduate modules student assessment it was divided into 50% for continuous assessment and 50% for the final EMA. The continuous assessment now comprised 1 TMA based predominantly on Blocks 1 and 2, and 3, and interactive Computer Marked Assignments (iCMAs) one each for Blocks 1, 2 and 3. The iCMAs were

weighted to form 10%, 10% and 20% respectively of the continuous assessment component, the TMA thus forming 60% of the continuous assessment. The final EMA still comprised a full written report and was equivalent in length and study effort to two TMAs but was now submitted electronically.

The iCMAs are a new feature for the topic but as with previous module CMAs each comprise around 20 exercise questions written to guide and check the students' learning progress with reference to the learning objectives of the module and particular study block. Each exercise involves a multi-choice selection with one correct answer among several plausible alternatives. Exercises may also include some practice activity of FEA. Students can have two attempts at each answer. For the first submitted attempt feedback is given in the form of either correct or not correct, the latter with a few hints and tips. The second attempt if successful is worth half the individual marks available. If not successful a second time the correct answer is flagged but no marks are given. Successful marks given are automatically stored as part of the individual student's continuous assessment score. At present, subsequent attempts evoke no feedback or marks although consideration is being given to providing more detailed feedback but delayed until after the cut-off date.

The TMA was marked by the students' own AL and each student received detailed commentary feedback and encouragement. As with all modules the ALs' teaching feedback and marking are themselves monitored by a central academic member of staff giving feedback reports to the ALs on their own performance. The final EMA reports were double marked by the students' own AL and a central module team member, again using the marking guide sheet shown in Appendix 2. Systems and provisions are in place to enable coordination of marking, any standardisation of marks, and third marking in the event of wide discrepancies in marks awarded by the first two markers. Detailed discussion by an award board (in the presence of an external examiner) sets the threshold mark boundaries for the continuous assessment overall score, final EMA mark and combinations of both for the awards of pass/credit, or distinction.

4.1 Issues with writing online study material for FEA

Although the team 'hit the ground running' in terms of topics and teaching material to be included there were some major challenges in adapting to the online format. It should be noted however that there are general issues with writing distance learning materials, online or otherwise, particularly in mathematical and technical subjects, which have been reported by Martin and Meehan (2009):

A key factor to understand when developing distance learning materials is that distance learning students are a disparate bunch. Thus, it is unwise to assume or expect that they have a common background of education, experience, or understanding of the subject(s) which they wish to study. Although provided with advice and recommendations that nominated 'pre-requisite' level courses in relevant subjects should have been completed, there is no guarantee with students that this will be the case, and even if so, there is even less guarantee that the required knowledge and understanding has been embedded, even with the best student.

It is important to note that this factor alone provides a profound difficulty for universities used to employing more traditional mechanisms to shortlist and enroll candidates for postgraduate-level courses. Inevitably, therefore, there must be some form of summary remedial teaching provided at the commencement of courses, if only to identify and then clarify common areas of misunderstanding, and agree on use of terms and units. However, as well as being self-correcting, this material will be of benefit to all students: this is to the extent that students familiar with the material will have little difficulty in progressing through it, without being held back by the slower student who will need and take as much time as necessary.

These aspects had been incorporated already in the distance learning materials for the previous modules, T525 and T884, thus it was necessary 'only' to convert and update the material to online format. This however still needed considerable resource and effort. For example, it was felt necessary to provide students with the options to download, copy and paste teaching material easily. Thus the material had to be rewritten in the form of page-sized 'chunks' or sections and converted from original or newly written MS Word files to the online system. In addition, as has been mentioned, the background theory and mathematics had to be written and word processed from scratch owing to the removal of the text book. This required meticulous preparation and proof reading at all stages, particularly as new errors could somehow be introduced between approved draft updates. Rendering of mathematical expressions in early versions of the online delivery system was 'patchy'. For example, some expressions were presented as images and so were not scaleable.

The proof reading was done by the original authors and also when possible by fellow academic team members who had not written the original material, effectively proofing each others' work. Also, an external proof reader, an academically qualified tutor/associate lecturer, was engaged to carry out this task. This was most helpful as the tutor was a textbook author in the subject area and importantly also a student support tutor for the previous courses and others and so was familiar with typical students' difficulties and requirements in following our distance learning teaching materials in engineering subjects.

The module, and its predecessor T884, are key components of profiles accepted by various engineering institutions for chartered member status. Academic authors themselves are suitably qualified and the learning activities were developed in line with contacts and discussions with practitioners in the field. For example, during the production and early presentation phases a formal external assessor/ examiner was appointed to oversee all module materials when in draft form and inspect a range of student EMA reports. The external assessor was a professor in the subject at another prestigious university.

4.2 Online module delivery of teaching materials

The Open University has moved over to a 'virtual learning environment' (VLE) for most modules and currently uses a variant of 'modular object-oriented dynamic learning environment' (MOODLE) as its core platform. In order to get teaching material on to the VLE, the university uses the proprietary 'extensible mark-up language' (XML) system editor 'Oxygen.' Teaching material is 'tagged' to provide a single source file which can have multiple outputs. For example, it can be rendered to the module website on the VLE, with each document producing one file, or series of webpages on the VLE.

Other outputs are also provided to students – PDF documents for accessibility and E-reader files (both .mobi and .epub) for delivery via a variety of external devices used by students these days. The challenge is to have a single source document or file which can be accessed via all regular means and still correctly display all mathematical equations, symbols, animations, graphics, video files, etc. as intended by the academic authors. Despite these difficulties, there are clear advantages in online presentation and delivery of teaching material for both students and suppliers of education in FEA.

4.3 Advantages of online delivery for learning

Online teaching material has advantages over traditional print material in terms of how students interact with the contents. Online material is fully searchable, instead of having to rely for example on an index

in a printed book. Students are also able to copy material easily to put in a format that suits them. Using the 'View as single page' option within the web documents in the VLE pulls all of the content for one document into a single web page. Students can then copy and paste text into a word document (or other format) and can add in their own comments or repurpose the material as they see fit – similar in concept to scribbling in a text book or printed course notes, but with the added advantage that such comments are also searchable.

Another advantage is that students have everything they need in front of them with no necessity to switch media, for example watching a video clip, making the learning experience more cohesive. As the earlier T525 and T884 audio-video materials were delivered on VHS tapes or DVDs, students would have to break off reading their printed module documents to load the video file they wanted to watch. In online delivery, the video file is embedded in the web document at the appropriate place, and is accompanied there and then with transcripts, subtitles and additional study notes.

There can also be more interactivity for the student in an online experience. For example, the aims and objects or learning outcomes are tested or reinforced in relevant places by specially written selfassessment questions (SAQs) with triggered reveal answers. There are also the interactive computer marked assignments (iCMAs).

This online system of distance education provision also allows the creation of a single 'hub' for everything related to the module. This can help both students and staff, for example in online tutorials, email and discussion forums outside the confines of formal tutorials.

The university also has a policy of ensuring accessibility to modules for students with disabilities. To help with visual impairment, transcripts are provided for specialist readers to supply audible descriptions of illustrations, mathematics, equations and teaching texts. Some dexterity with a computer mouse is necessary so it is hoped that keyboard operation for exercises will be developed.

4.4 Advantages of online delivery for production

Books and hard copy study units or booklets are costly to paginate and produce. Some first-level Open University modules have thousands of students which may help a little with piece prices, but specialist modules of the form of T804 typically appeal to much smaller groups of students, which means that print runs have to be small and relatively expensive. Storing and shipping such hard copy module materials also incur costs. Obviously, these sorts of costs are not borne by online presentation.

Another important benefit with online delivery, which is an advantage for production staff and students, is the ability to fix any errors quickly or update material without having to send out individually addressed errata slips or wait for a reprint run of new hardcopies. Production schedules are also improved with online delivery – as time for books to be printed and shipped does not have to be factored in.

4.5 Comparison of print and online delivery with student take up

Online delivery poses different cognitive challenges for students, particularly if they're not used to online learning. For example, it can be much harder to quickly assess how much work there is in an online document without opening every single page of it. While students can flick through a 30-page booklet and think 'there are 30 pages of reading here with 5 activities to complete,' it can be much harder to estimate how long it will take to read a set of webpages. One webpage might have 100 sentences and

a couple of illustrations, another page might have 3000 words, yet another might be half a page of mathematics.

Because of this, it is important in production to try and standardise page lengths as much as possible – although inevitably some topics or subtopics are longer than one page will allow. Section breaks do not always naturally fall in such standard templates. Equally, from the students’ point of view it can be harder to break and resume study with the same ease as returning to a physical bookmarked page in a hard copy document.

Figures 4 and 5 show the general pattern over the years in terms of numbers of students starting, finishing and passing the modules. Note that the pattern is reasonably consistent throughout for the predecessor T884 and new presentation online format of T804, in terms of start and finishing percentages. The large take up in 2013 perhaps reflects student planning, knowing that the original module was coming to its end, a trend seen for other modules historically. Equally the relatively low take up in the first year of the new module (2014) reflects trends observed for other new modules historically, as the previous modules ‘soak up’ pending students while others wait to see how the new module beds in.

Allowing for the changeover period, however, the recent three years of presentation and performance results shows that the online version is sustaining higher student numbers than the general run of the hard copy predecessor (for example compare years 2008–2012 with 2015– 2017).

Figure 4. Annual results of Post-graduate FEA module, previous hard copy teaching version

Figure 5. Annual results of Post-graduate FEA module, online teaching version

4.6 Feedback of student performances

Feedback of student performances, experiences and satisfaction are gathered in four ways. First, the university's own Institute of Educational Technology (IET) provides detailed statistical surveys for each presentation of a module. These comprise data such as numbers of students registered on the module at its start date; students who completed the module; students who submitted a final assignment; students who passed/gained a credit; students who gained a distinction and various percentages based on numbers registered at the module start date.

Second, the Faculty sends each student a satisfaction survey which invites responses to questions such as

- What aspects of teaching materials, learning activities or assessment did you find particularly helpful to your learning?
- What aspects of teaching materials, learning activities or assessment did you find not particularly helpful to your learning? We would welcome any further suggestions or comments to consider for future editions of the module.
- Do you have any other comments to add about your study experience on this module?

It is difficult to evaluate the numbers of student responses as it varies from year to year but it is fair to say that a majority of students do take the trouble to summarise their experience with the module. Incidentally, starting with the previous module, T884, the central academic module team personally funded a small cash prize to be awarded annually to the student with the highest overall assessment score. This was later funded by NAFEMS along with a prize certificate, and it is fair to say that feedback from the winning students (and their employers) was generally welcome and positive!

Thirdly, there are the formal award board and other meetings to discuss marks, the setting of marks threshold boundaries, dealing with any issues that may have arisen in presentation etc. These are conducted in the presence of the external examiner who would also receive sample EMA scripts beforehand. For a new presentation, there is also a module team review meeting to highlight and resolve any issues from presentation and performance throughout the year and as a result of decisions of the award board.

Fourthly, a member of the module team formally monitors and reports the performances of students and ALs during the presentation to note how assignments are being tackled and marked. There are also of course informal contacts with the ALs at any time, although generally speaking the students deal directly with their own AL rather than the central module team.

As an example of responses to feedback one aspect that has been incorporated in presentation is the adoption of more 'hands on' exercises in addition to the assessment tests (iCMAs, TMAs and the EMA). These take the form of the self-assessment questions and exercises (SAQs) familiar to Open University students on other modules. In particular, there are more software exercises aimed at preparing the students' computer modelling skills for the EMA.

4.7 Issues with online delivery for students

Surveys show that many students still prefer hard copy print as being easier and quicker to read, so experiments with print on demand have been implemented. These give the students the options of what to print and of course reduce publishing, warehousing and distribution costs at source. There were requests to offer teaching materials in the form of PDFs to ease print capability.

For some students, it proved difficult to maintain the quality of mathematical expressions and terminology when cutting and pasting to create files to suit their own learning paths and 'note taking.' Because of the mathematics content in parts of the presentation, including many diagrams and equations, it was necessary to insert false breaks in presentation to suit the online web page based format but which were not in themselves in appropriate places. When running the FEA programmes or models it was necessary for students to have at least two screens operating if following teaching notes along with running the software. This proved difficult for some.

Involving a third party supplier of software can mean that aspects of the module (e.g. the FEA exercises) are locked to specific personal computer formats and specifications, removing some of the claimed versatility of the online approach. The capacity needed to download the software for T804 was 5 GB and back up installations were provided on DVD ROMs for individual installations if needed (none so far). It is important to use a 'standard' or common commercial code as would be used in industry and to be robust enough to stand a few years as being a teaching resource. For example, it would be too much to expect students and ALs (and the module team) to deal with open source or a variety of alternative FEA packages and maintain consistent support and teaching quality and relevance to the other teaching content. In working with software suppliers it is important to define a version specification that will not change for an agreed presentation period of the course.

The software suppliers usually have restrictions on licensing and supply. For example, there could be educational versions with cut down capabilities and restrictions on countries and locations of students. Although the online approach could facilitate worldwide presentation, ironically the supplier used would only allow up to 10% of students from the EU and no others from outside the UK.

All courses and modules, online or otherwise, have a presentation chair nominated to oversee maintenance and annual presentation, including the preparation of assessment projects. Under this remit is the task of ensuring that the FEA code and related teaching materials are in harmony and preferably remain generally unchanged for say 3 years or so. The life of a module will be something like 9 or 10 years so there could be 3 're-writes' to be addressed. This is similar to the previous systems where a print run of hard copy materials would represent 3 years of teaching before ordering reprints. On the other hand, with the online presentation model minor changes can be more easily accommodated, avoiding the need for supplementary copy print runs or errata slips that may have been required in traditional offerings. It is considered reasonable enough to 'freeze' the education version of the FEA code for such typical interim presentation lives of 3 years or so. Thus it is possible to respond reasonably regularly if need be to requests and observations for changes following feedback from students, authors, associate lecturers and external examiners.

Detailed comments and notes from students were studied following first presentation and overall were mostly positive – in particular, the help and support of ALs were frequently mentioned. The ALs themselves were also positive in their judgments of the success of the new teaching presentation, being in a position to directly compare the approaches of T804 and its predecessor T884.

4.8. Issues with online delivery for production

As mentioned above a key bottleneck is in the transfer of material written and produced by the original academic authors to the online presentation format. Apart from the discipline of thinking and writing in 'chunked' sections for delivery on single webpages, the physical processes in getting the material down in usable form involves a number of stages and staff with specialist skills. This was particularly the case with the mathematics and equations with associated Greek symbols, super scripts, subscripts, variable italics, units, etc. requiring detailed typing and word processing skills. Also, detailed proof reading was necessary at all stages not just for checking human typographical errors but for unexplained new errors introduced between versions and updates, seemingly automatically by the software itself!

There are further constraints in adopting and using third party supplied software. There are license considerations, support agreements, the need for installers to cut down large downloads for educational versions (e.g. with element and node number limits). Importantly and somewhat ironically there is the need to 'freeze' the version of the software so that students in future presentations will have the same learning experience. Version updates inevitably introduce unwanted and unexpected changes which even if minor in form can still confuse and bewilder the student working at a distance when instructions and accompanying text apparently and suddenly mismatch.

A more general issue with some students is a lack of understanding or knowledge of basic engineering science or principles. To this end, the module contains a revision section on normal mode vibration analysis of beams. Potential students are also encouraged to undertake a diagnostic quiz before embarking on the module and in promotional materials there are ample descriptions and warnings of the high level of study required for the advanced theory at MSc level.

The university is also planning to introduce more online activities in the undergraduate modules using the same FEA software tools. This is by way of introducing students to the mode of study in T804 and to cover more of the basics of mathematics and engineering science they will be meeting.

5.0 Conclusions

For many years the Open University has had an interest in and has presented supported distance learning education modules in finite element analysis. Modules at postgraduate level are aimed at giving users a qualified understanding of the assumptions and limits implicitly and explicitly embedded in the method. This approach is considered necessary to enable safe and effective use of FEA now that computer software and systems have become so widespread and relatively easy to use without such real understanding.

The delivery method of courses and modules has included broadcast television and radio programmes, physical packs of printed teaching materials, VHS video tapes, DVDs, etc. but is now adopting fully online presentation.

The online format enables the inclusion of written study materials, study guides, detailed mathematical analysis, filmed case study discussions and real software code analysis programmes to be incorporated at one interface.

The online presentation gives feedback and support by allocated tutors, a module website, student forums, etc.

Assessment philosophy has been mainly by tutor-marked assignments and a final examinable project or assignment. In both cases, these are based on the analyses of engineering components which are relatively simple to model but contain challenges and issues of analysis which are anything but simple. These include material properties, boundary and restraint conditions, load applications, etc. Other computer marked assignments reinforce more specific teaching topics.

An outline syllabus is given highlighting the topics and subjects addressed in presenting an introduction to the basic principles and applications of the finite element analysis method for stress, thermal and dynamics analysis.

Observations are given on the processes, routes, structure, advantages and disadvantages and challenges of going over to fully online presentation of tried and tested distance learning teaching materials in the subject area.

Analysis and feedback of student performance show patterns of results that are consistent for both previous hardcopy and new online presentations. Indications are that the online version of teaching such a highly involved mathematical subject is producing satisfactory results generally higher than for the previous teaching format.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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Appendices

Appendix 1: Overview of syllabus of OU Post-graduate distance teaching of finite element analysis (FEA).

BLOCK 1:

Introduction to FEA Theory, Procedures and Safe Practice: giving the basic theory of finite element analysis and introducing the general procedures to carry out a safe, correct and accurate analysis. The block also covers the introduction and use of a real software system. From the start there is emphasis on the need for comprehensive evaluation and checking when interpreting and reporting results. Detailed FEA exercises are provided, along with revision of stress analysis and materials properties involved in modelling and conducting FEA in structural applications.

BLOCK 2:

- (A) Linear structural: Provides a revision of matrix methods of analysis and various methods of solving sets of linear equations. Introduces two and three-dimensional formulation of element types, properties and shape functions, using direct, variational and weighted residual approaches. Many FEA exercises are provided including how to conduct a linear stress analysis of a loaded component.
- (B) Heat transfer: introduces the basics of one and two-dimensional heat transfer including conduction, convection and radiation. Uses an energy balance equation approach in the F.E. formulation of heat conduction and thermal stress modelling. A number of FEA exercises are provided including how to conduct a linear thermal stress analysis of a loaded component.

BLOCK 3:

- (A) Non-linear Analysis: introduces material, boundary and geometric non-linearity issues. Some aspects of modelling non-linear behaviour in FEA are introduced with exercises provided.
- (B) Dynamics: Systems of one- and two-degrees of freedom and flexural vibration of slender beams are reviewed. Basic principles of finite element vibration analysis are introduced.

Appendix 2. Example guide mark sheet used by markers of the end of module assignment (EMA).

Report & marks for T804 EMA. Student:

PI:

% Marks available % Marks awarded

1. Report quality		
a. Presentation quality	4	
b. Table of contents	2	
c. Summary	2	
d. Conclusions	2	
Sub total	10	
2. Stress analysis		
e. Approach and assumptions	12	
f. Modelling and meshing	12	
g. Boundary conditions	8	
h. Use of symmetry	3	
i. Verification calculations	5	
j. Comments and discussion	10	
Sub total	50	
3. Modal analysis		
k. Approach and assumptions	8	
l. Modelling and meshing	8	
m. Boundary conditions	6	
n. Discussion of symmetry	3	
o. Verification calculations	5	
p. Comments and discussion	10	
Sub total	40	
Overall total	100	Awarded:
4. Comments		

For the stress analysis:

For the modal analysis:

Overall:

Marker: _____, date: _____