An open approach to educational resource development, with a specific example from structural engineering

Comerford, L
Postgraduate Student, University of Liverpool, Liverpool, UK

DeAngelis, M
Postgraduate Student, University of Liverpool, Liverpool, UK

Mannis, A
Lecturer in Construction Management and Sustainable Engineering, University of Liverpool, UK

Beer, M
Professor of Uncertainty in Engineering, University of Liverpool, Liverpool, UK

Kougioumtzoglou, I
Lecturer in Uncertainty and Engineering, University of Liverpool, Liverpool, UK

Conference Topic: Technology in Learning

INTRODUCTION

A detailed account of how an interactive learning software package was developed to address identified knowledge gaps amongst undergraduate engineers at the University of Liverpool (UoL) is presented in this paper. A primary objective, established from the outset, was not only to meet the needs of the local university, but also to consider dissemination and applicability of this package for other institutions. There were three main objectives. First, the software needed to teach the subject matter – in this case, a key concept in structural engineering – with little or no additional input from the lecturer; the user becoming an independent learner. Second, a system was required to ensure students completed a list of tasks (interactive problems / questions) set in the software, and that this could be checked for progress in understanding. Finally the package needed to be applicable as much as possible for other institutions, home-based in the UK and importantly in a global context.

The learning package takes the form of a structured presentation having a series of in-built interactive elements. These elements consist of simulated experiments and questions, requiring input before the user may progress. The primary purpose of these tasks is to keep the learner engaged with the material on-screen, i.e. they cannot complete each stage unless they have read and properly understood the tasks. The development team at the UoL partnered with a number of external institutions, thereby providing a network of academics to offer feedback in creating the package. This gave rise to an iterative and collaborative development process, through which the e-learning package has been able to expand. Rather than evolve into a narrow institutional-specific application, it has now become a comprehensive tool with use by others across the international engineering community.

1 THE RATIONALE: ENHANCING THE STUDENT EXPERIENCE IN ENGINEERING

The initial motivation for creating an electronic-learning (e-learning) application came from a specific need within the School of Engineering of the host institution, the UoL. Here, as part of a semester-long 12-week module titled 'Solids and Structures II', second year undergraduate students were required to attend a two to three hour associated lab session which was designed to give a practical understanding of the principle / concept known as Euler buckling [1]; the lab session titled 'The Buckling of Struts'. Previously in 2013, the authors had identified important knowledge gaps between what these students should know upon starting the lab and what they actually did know. Those gaps in knowledge had multiple causes. Some students had transferred from other universities, and so had not covered the necessary pre-requisite content in their earlier years of study. Further, due to timetabling constraints, the lab would run throughout the semester for the module it supported. This meant that students attending the lab at the end of the semester had covered significantly more of the related content than those attending at the start. Finally, since lab sessions such as this constituted a relatively low proportion of marks compared to end of year exams, the students rarely revised any related content prior to attending. These problems are not specific to the UoL; with one proposed solution used by many institutions being the provision of a ‘pre-lab’ [2]. A pre-lab is usually an educational resource to ensure a student gains pre-requisite knowledge to properly understand and benefit from the lab session. The pre-lab may take many forms: sometimes a single page document is sufficient; for others, something equivalent to an entire book chapter may be required. Multiple forms of media are also utilized, and in the case described here an e-learning software approach was taken.

2 EDUCATIONAL PRINCIPLES: MAKING USE OF E-LEARNING

In an ideal scenario, the pre-requisite content for the lab would be taught by a lecturer. This is because in many cases, for the students involved, preparing for the lab would require more than simply revising previous work, but also learning new concepts altogether. Unfortunately, further teaching by a lecturer is seldom possible, due to timetable constraints and cost; and this was also the case for the pre-requisite theory directly associated with the topic of buckling in structures. Therefore, ideally the pre-lab needed not only to provide the relevant information, but also to offer a sequenced learning experience without the explicit input of a lecturer. Although it is possible to create materials that provide effective experiences through many forms of media, it was felt that an e-learning approach gave the most flexibility; the primary reasons based on the following educational principles:

2.1 Addressing Multiple Learning ‘Styles’

Although the lab session had a rather specific and also closely related set of learning outcomes to its associated lecture-based module, the pre-lab needed to be comparatively broad, in approaching the topic (in this case buckling) with a combination of mathematical derivations, experimental procedures and conceptual understanding. When designing an e-learning tool, instead of approaching every learning objective in the same ‘linear’ way, different combinations of multimedia tools can be packaged together with particular approaches to targeted problems. For example, the best way to explain one concept may be through studying a diagrammatic representation of it with accompanying text; then a subsequent concept may be better explained by visual enhancement, such as animation; and so on.

2.2 Building on Students’ Different Levels of Pre-Requisite Knowledge

Video lectures are a popular method of addressing knowledge gaps for students, particularly when working around timetable and cost constraints. If a student cannot keep up with the content in a video lecture, they may replay sections. But, unless the video has been designed specifically with pausing and replaying in mind, this is likely to become tedious for the student. In a similar respect, if the student feels that the pace is too slow and wants to skip forward, this also presents difficulty, since the learner may not know where to skip to, and whether they are likely to miss small chunks of important new information whilst doing so. However, with many e-learning packages, students are able to work at their own pace. Therefore these problems are addressed to a large extent, even without specifically tailoring a piece of software to the distinctive pace of different learners.

2.3 Ensuring Interactivity and Engagement

Without e-learning tools, the only main form of feedback offered to students comes directly from staff. Within a university system, that may be assessors, teaching assistants, lecturers or technicians who give verbal or written feedback on assignments. This is another incredibly time-consuming process which can be avoided in some cases by deploying interactive software. At a very basic level, interactive tools can comprise check-boxes and radio-buttons, designed to ask students questions and to provide targeted and live feedback based on the answers. More complex software can provide full scientifically accurate simulations with extensive teaching potential, if utilized well.

If a student does not have a core interest in a particular topic, it can often be difficult to keep them engaged in the subject matter without the pressure of an exam or highly-weighted piece of assessed work. E-learning software has the potential to be engaging and even fun, despite situations where the student may not have been previously interested in the content communicated by the package [2].

2.4 Incorporating Progress Monitoring Options

Even if assessment is not a primary objective, there are advantages to monitoring student progress through taught content. By opting to use e-learning software, numerous systems can be implemented to allow an assessor to check whether a student has completed a set task, how long it has taken them to complete the task, and how well they did. With effective implementation of an in-built monitoring system, comprehensive statistics can be collected on learner progress with limited assessor input.

3 COLLABOARTIVE PRINCIPLES: DEVELOPING ‘OPEN’ SOFTWARE

One key advantage of creating ‘open’ learning software in a collaborative environment is that it allows for adaption of the originally-produced package. Modifications by third parties have the potential to greatly improve the product (educational tool) with negligible cost to the original developers [3]. Distributing free, open software also encourages others to contribute freely to the original outputs. In addition, making software freely available is likely to increase the user-base far beyond that of an internal or paid-for product. This in turn can act as an effective promotion for the consortium of collaborative partners involved, thereby increasing their visibility and reputation; as seen in the relatively recent popularity of massive online open courses (MOOCs) [4].

A large number of open educational resources (OERs) that are currently available electronically, whether they come from universities or industry, were not originally designed to be open; i.e. they were developed in-house to address a very specific problem, and then released to the public under an open license at some point in the future. The result is that although similar topics may be taught across multiple educational institutions, slight differences in the syllabus or teaching style may render external OERs unsuitable, even if as much as 90% of the content was relevant [4]. Furthermore, although released under open licenses, the use of specialist, paid-for software to create and edit these resources (e.g. graphical / video / programming tools) often makes them difficult for other institutions to adapt or to re- purpose (even assuming source files are available).

The original motivation for the e-learning package here was again to create a specific application to address an identified problem. In order to avoid building this package for purpose only at the UoL and then releasing it openly after completion, third parties were considered from the outset. By including several partners known to teach the topic of buckling in discussions on how they would most likely use the pre-lab and its software, the development team was able to draw extensively on their expertise to build a product that could then be more easily utilized by others. It was assumed that once finished, if the software was ready to be integrated into courses at a number of partners without many further changes, other institutions (not involved in the original cycle of development) would find the e-learning tool far more applicable than if it was solely created as a pre-lab for learners at the UoL in mind.

4 THE ENGINEERING TOPIC / CONTENT: BUCKLING OF STRUTS

In structural engineering (theory of structures), buckling commonly refers to mechanical instability of compressed elements. In the majority of cases, buckling is followed by sudden structural collapse or partial failure. Buckling instability is understood as a sudden shift (bifurcation) in the solution of the equations of static equilibrium. Thus, from a mechanical perspective, buckling occurs when two conditions are met:

- The static configuration of a compressed element rapidly changes from axial to flexural;
- The axial stiffness happens to be greater than the bending stiffness.

If one of these conditions is not met, buckling cannot occur. While the latter condition applies to the majority of columns or compressed members where the slenderness ratio (effective column length / least radius of gyration) is large, the former condition occurs mainly because of two reasons:

- Inherent variability of the structural members, such as heterogeneity of material or geometrical imperfections;
- External factors, such as load perturbations, eccentricity in the load or temperature gradients.

From case to case, depending on both the type and extent of the aforementioned phenomena, buckling can manifest in many different ways. By this definition, buckling instability refers to the steep drop of load-carrying capacity of a compressed element when the static configuration changes instantaneously from that of axial to flexural state/condition. Clearly, the larger the gap between axial and bending stiffness, the more evident and catastrophic the buckling failure would be expected. The theory of structures investigates the state of transition between the two configurations of equilibrium, and provides the equations for a quantitative assessment. Typically, the assessment of buckling is reduced to a calculation of the critical load triggering the buckling failure.

It is essential that students at the end of a course module which teaches buckling not only have in mind how to calculate the critical load for a variety of conditions and structural elements, but have also grasped most of the theory leading to the calculation of the critical load. This therefore ensures that the learner is able to generalise and apply the concept of buckling when different conditions arise.

The importance of buckling is undisputed among scientists and engineers. The ever growing needs for lighter and stronger structures, as they appear in aircraft, skyscrapers and auto-vehicles, highly motivates the consideration of buckling from teaching institutions and companies. Despite the importance this topic has for engineers, most often buckling is taught as an independent, sometimes marginal subject area within the wide range of course content associated with structural engineering. This can be attributed to the fact that buckling is an advanced engineering topic which needs to be addressed with a sound mathematical basis. In fact, it combines advanced engineering concepts, such as stiffness, load-bearing capacity and elasticity, with advanced mathematical concepts, such as stability theory and differential equations.

In many cases, a major challenge for students is to gain confidence with buckling from the perspective of mathematics. The authors found a key motivation for developing this learning package was that a majority of engineering students at the UoL did not have theoretical foundations that were sound enough to be able to fully handle the topic. Furthermore, increasing the number of taught hours dedicated to introducing stability theory was not feasible. As a result, the mathematical basis of buckling was often skipped, highly simplified, or covered too quickly for students. These factors strongly convinced the authors to create an e-learning package, in partnership with a number of institutions beyond the UoL, that was then capable of teaching buckling from the dual perspectives of physical / practical intuition and the underpinning mathematics.

5 THE DEVELOPMENT PROCESS: CREATING THE E-LEARNING PACKAGE

Clearly there are many forms an e-learning application may take, and there may be countless teaching styles that effectively approach any taught subject. The following section of this paper is not meant to be seen as a guide for creating effective e-learning software, but instead to highlight an example of a successful approach. An important point to note is that the development team was small and used relatively simplistic and accessible programming techniques (i.e. Adobe Actionscript 3) to build the package in a short time-frame, drawing also on regular engagement with external partner institutions.

It was decided that the first draft of the package would comprise several small-scale interchangeable sections. These sections would be self-contained mini-applications that would utilize a combination of two-dimensional interactive animations, non-interactive animations, radio-button style questions and standard text. The thinking here was that diverse activities, and a range of difficulty levels, could be targeted simply by choosing the most ideal combination of sections from the core set of developed electronic content that made up the package (thus widening the potential future audience). The team then made a list of basic learning outcomes based on the underpinning theory. This was followed by a lesson plan which was built around teaching the associated content. By considering the section-based template and the available building blocks of content, the lesson plan was converted into an e-learning tool blueprint. From this, the initial implementation of the application originated, which was circulated amongst partners for initial testing and feedback relating to both content and sequence of learning.

In progressing from the lesson plan to the application blueprint, several different teaching themes emerged and were implemented in the first draft. Four of these themes considered to be amongst the most successful that emerged from the partner consortium are highlighted with examples below.

The first of these themes, and arguably the easiest to implement, was the use of a simple visual presentation approach to communicate information. For the most part, these areas of exposition could be lifted straight from the pre-planned buckling lesson plan and directly implemented. The user would be presented with on-screen text and accompanying static/animated diagrams (e.g. Figure 1). In order to advance through the textual content and diagrams, the user would then press the space bar on the keyboard. This became a running theme across all the developed sections in the e-learning package.

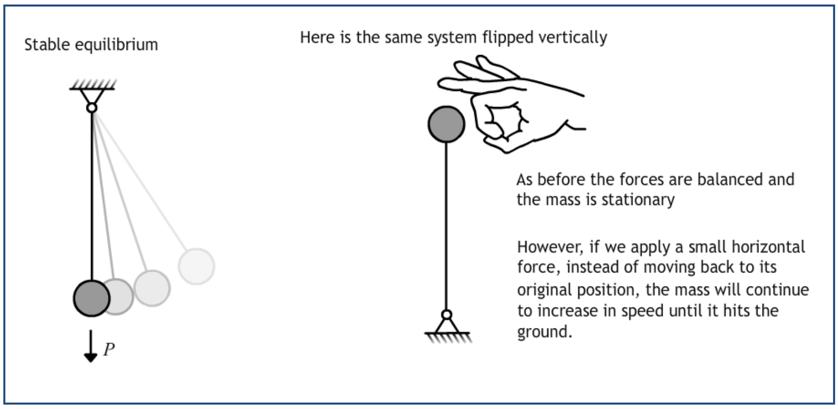

Figure 1. Information presented as a series of textual content and diagrams

The second theme was the use of stylized interactive on-screen tasks. This required dynamic graphics that reacted to user input, rather than having static animations. These could range from simple puzzles to full experimental simulations. Figure 2 shows a simulated buckling experiment requiring user input to plot a graph of load vs compression. Due to additional programming complexity, designing and implementing these features was the most difficult and time-consuming element of the development process. Nevertheless, these outputs have proved to be the most engaging sections for students from implementation and testing across all partners, and it was also possible to re-use certain parts, such as the buckling experiment in Figure 2 in several different contexts.

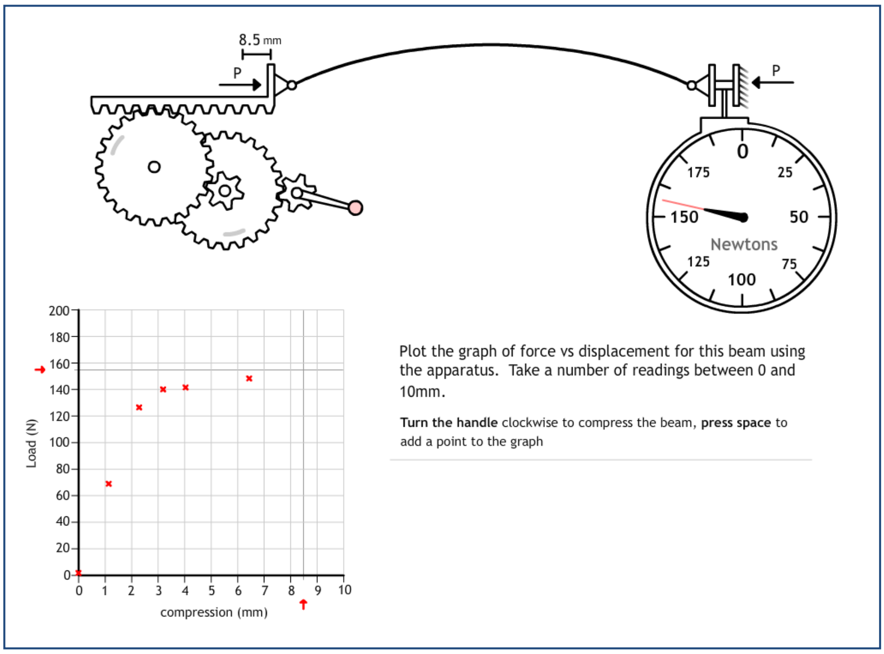

Figure 2. The inclusion of interactive experimental-based simulations

The third theme to emerge was the continuous high frequency use of multiple-choice questions (MCQs). This is possibly the most integral part of the application from a learning perspective. In order to advance through the various sections in the package, the user must press the space bar when prompted. The user is only prompted when a current activity has been completed; this could be a significant interactive element, such as the experiment above in Figure 2, or more commonly a MCQ. The implementation here was relatively straightforward: if the user obtained an incorrect answer, they would have to try again (e.g. Figure 4.a); but with a correct answer, they would be allowed to progress (e.g. Figure 4.b). As the MCQs were considered to be a learning tool rather than an assessment method, this gave rise to two innovations in their use. Firstly, these MCQs could be used simply to keep the user concentrated and on-track. By asking questions based on the current content on-screen, the user would then be required to focus (e.g. Figure 3). Even if these questions were not related to the core learning outcomes, they presented an effective tool for ensuring the user had read and understood everything on the screen (i.e. even if the user was tired or bored, they must concentrate to some extent in progressing to the next screen). Secondly, because there was to be no penalty for obtaining an incorrect answer, these MCQs provided an alternative thought-provoking method of stating a concept of knowledge. When a fact needed to be stated, rather than simply providing the information, the student was asked a question to which the correct answer was that fact.

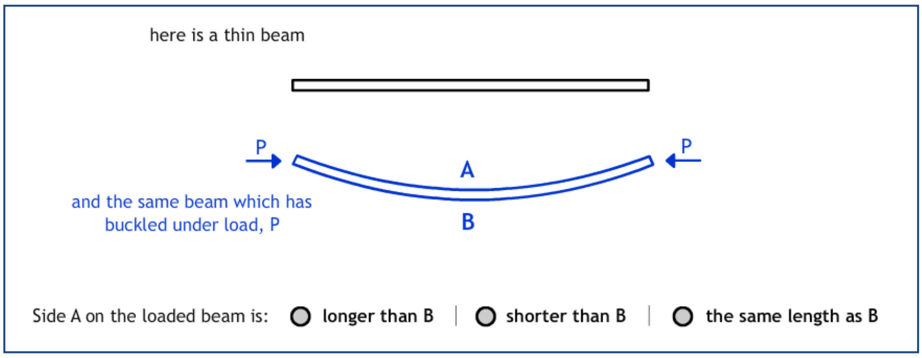

Figure 3. MCQs for the learner to determine their level of understanding

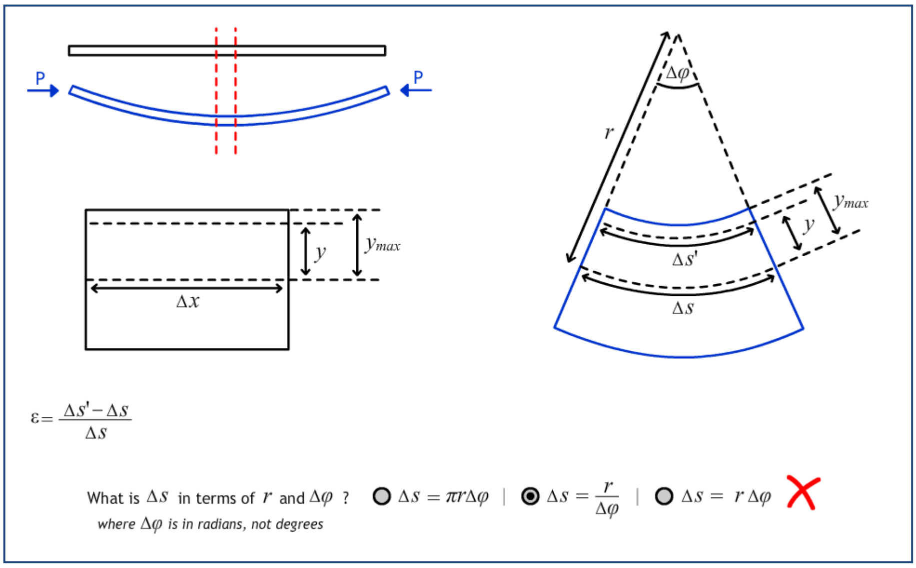

Figure 4.a. An incorrect MCQ prompts the user to try again (without any penalty)

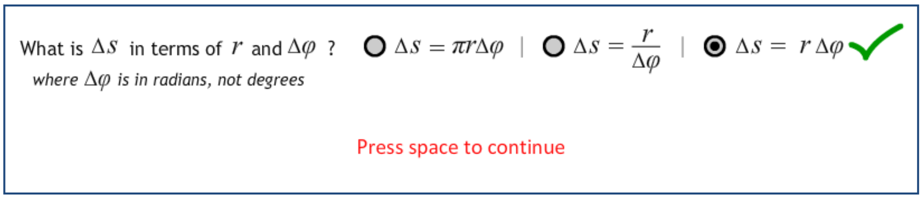

Figure 4.b. A correct MCQ allows the user to progress further in the package

The final theme to be highlighted from the consortium development process was the way in which mathematical derivations were presented. It was agreed that an important part of such derivations could be based on an extensive use of MCQs. Since there could well be no lecturer to explain or answer learners' questions, mathematical equations were derived in very small steps, some of which would be considered too minor and knowledge already assumed in a text book. By making the derivations as granular as possible, and by also having MCQs at every stage, the aim of the development partners was to maximize the number of students who would follow the package and understand it in full through to the end. For example, four MCQs were used to build up to the equation for the moment over the cross-section area, $\int \sigma dA$; see Figures 5.a and 5.b.

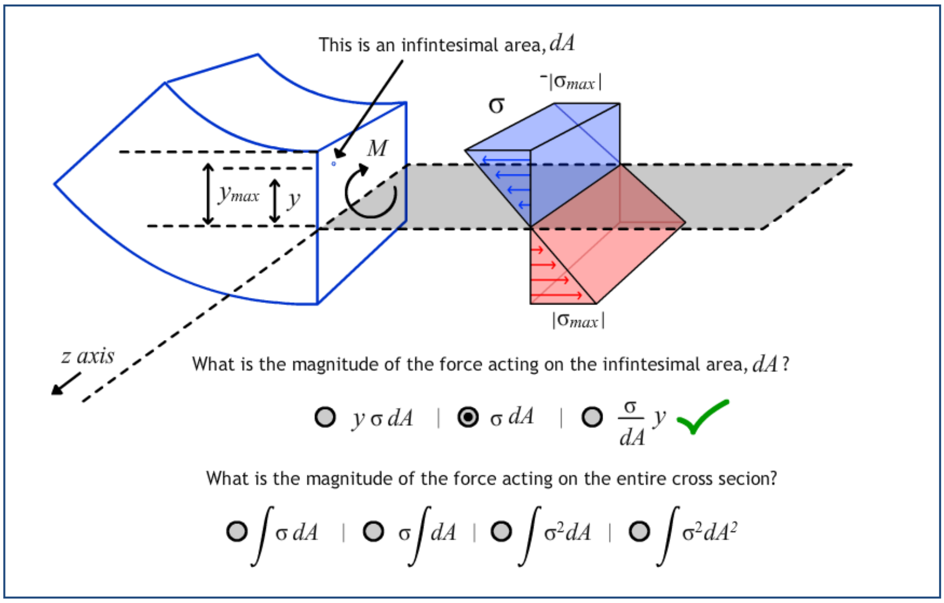

Figure 5.a. MCQs building expression for force on a cross section

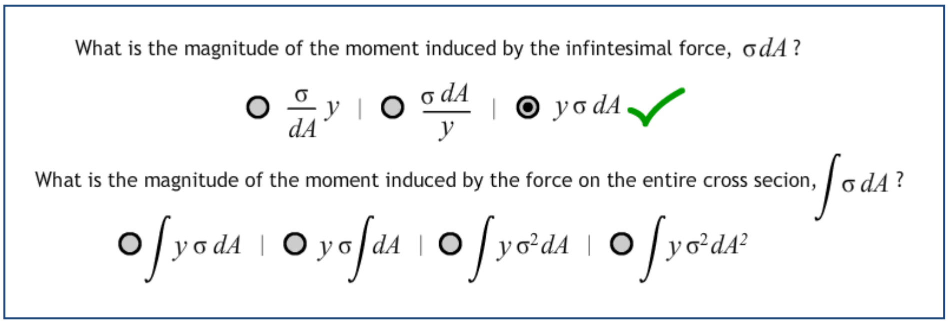

Figure 5.b. MCQs building on previous steps leading to moment expression

6 TARGETTING THE END-USER: ENSURING STUDENT ENGAGEMENT

Regardless of how interesting and effective teaching content could be, there can often still be problems when setting non-assessed tasks for students. It is the experience of the authors that if there is no credited value attributed to a task (i.e. devoting time to a pre-lab activity), then many students are likely to avoid it. As a consequence, the proposed solution here was to use some method of checking whether a particular student had completed the pre-lab, and to give credits or apply penalties appropriately. However, although creating a bespoke database login system for students had been suggested as a potential addition, such implementation and administration was considered a future activity of the partner institutions. In addition, whilst integration with a university's own virtual learning environment (VLE) was a possibility, this was not considered to be in-line with the open nature of this consortium of developers. In the end, the adopted solution was in fact incredibly simple to implement, and proved to be highly effective. When a student reaches the end of the final section in the pre-lab software, an individual code is displayed on the screen. This code is based on a simple algorithm which can be validated by anyone familiar with how it was generated. All codes are also unique. By owning a valid code, the student can prove that they have then completed the pre-lab.

Taking the UoL as an example from the partner consortium, the buckling of struts lab session is worth 10% of the ‘Solids and Structures II’ module; with the proportion of this award based on either a written report or online assessment after the session. The students were informed by email (and with a reminder one week before their lab) that they must read a specific book chapter on the subject of buckling in advance of undertaking the practical lab session, and that they would be tested on their knowledge orally at the start of that session. They were also instructed that if they could not answer any questions set by the lab demonstrator, that they would receive zero marks regardless of their quality of work. Alternatively, these students were given the option of bringing the code from their completed pre-lab; and told that by arriving with a valid code they did not then have to answer any questions from the lab demonstrator.

From February to May 2014, during the second semester of this academic year at the UoL, almost 300 students attended the lab session titled ‘The Buckling of Struts’, with 98% of them starting the lab by having produced valid pre-lab codes. This was seen as a tremendous success, since not only had the students undertaken an extra 30 to 45 minutes of work before coming to the lab by completing the learning package in full, (since at the UoL all eight of the e-learning sections comprising the pre-lab were used), they also had a much greater understanding of what they were going to subsequently do and learn in the lab session; which had not been the case in previous years. Moreover, due to the simplicity of the unique code system, the additional administrative workload required to ensure that each student had completed the pre-lab was virtually non-existent. This has been borne out from feedback provided by these UoL students at the end of the module, relating to the lecture content, its associated lab on buckling, inclusive of the pre-lab which had been developed and implemented this academic year.

In summary, feedback comments received at the UoL were largely positive in relation to the pre-lab, with three main advantages consistently mentioned – and a sample of that evidence included here, taken from learner statements. Students felt “prepared in advance of the lab session”, and reinforced this by “being able to get on with doing [the lab] independently [of the demonstrators]”, whilst also completing the lab session “more confidently” and “quicker compared to many other labs in the School [of Engineering]”. Finally, from working through the pre-lab, these learners were able to now “better understand the principles of buckling”, and could “connect the theory [of buckling] to practical engineering”.

REFERENCES

[1] Euler, L. (1960) ‘Additamentum I de Curvis Elasticis, Methodus Inveniendi Lineas Curvas Maximi Minimivi Proprietate Gaudentes, Lausanne’ *Opera Ommia I*, 24.

[2] Dales, R., Lamb, F. And Hurdle, E. (2010) ‘*Engineering Graduates for Industry: University of Liverpool, School of Engineering Case Study*’; (Royal Academy of Engineering: London).

[3] Taylor, I. and Mannis, A. (2008) ‘*Working in Partnership with Students: The Summer School at Cambridge; A Case Study from the UK Centre for Materials Education*’, (UK Centre for Materials Education: Liverpool).

[4] Crawley, E., Malmqvist, J., Ostlund, S. and Brodeur, D. (2007) ‘*Rethinking Engineering Education: The CDIO Approach*’; (Springer Science: New York).