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article

Utilising database-driven interactive software to enhance independent home-study in a flipped classroom setting: going beyond visualising engineering concepts to ensuring formative assessment

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The concept of formative assessment is considered by many to play an important role in enhancing teaching in higher engineering education. In this paper, the concept of the flipped classroom as part of a blended learning curriculum is highlighted as an ideal medium through which formative assessment practices arise. Whilst the advantages of greater interaction between students and lecturers in classes are numerous, there are often clear disadvantages associated with the independent home-study component that complements timetabled sessions in a flipped classroom setting, specifically, the popular method of replacing traditional classroom teaching with video lectures. This leads to a clear lack of assurances that the cited benefits of a flipped classroom approach are echoed in the home-study arena. Over the past three years, the authors have sought to address identified deficiencies in this area of blended learning through the development of database-driven e-learning software with the capability of introducing formative assessment practices to independent home-study. This paper maps out aspects of two specific evolving practices at separate institutions, from which guiding principles of incorporating formative assessment aspects into e-learning software are identified and highlighted in the context of independent home-study as part of a flipped classroom approach.

Keywords: Flipped classroom; formative assessment; e-learning; interactive video lectures; independent study; learner engagement; student feedback

1. The case for the flipped classroom

The ability to apply a mixture of mathematics, computing, practical skills and a range of other knowledge to deal with diverse and often unfamiliar challenges / problems is core to the subject of engineering. In this regard, a significant objective in many elements of the engineering curricula (such as courses and modules) is for students to develop relevant problem-solving skills. It is clear that one of the most effective ways of developing these skills is to repetitively practise solving such challenges / problems. In a traditional teaching model, this sort of practise would take place outside of the classroom in the form of marked or unmarked assignments. However, in recent years the concept of a flipped classroom approach (e.g. Bergmann and Sams (2012)) to teaching in engineering has

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gained considerable interest (e.g. Svensson and Adawi (2015); Triantafyllou, Timcenko, and Kofoed (2015)). In a flipped classroom model, the traditional lectures and homework assignments are reversed; in the sense that lecture material is instead regularly delivered as part of homework tasks, thus freeing up the timetabled sessions for group problem-solving, discussions, questions and answers.

This approach is particularly useful in engineering, since many problems lend themselves well to group discussions. Further, after completing their studies, students moving into professional engineering careers are often required to work as part of larger groups, and so preparing them with similar experiences is advantageous. It is also true that many engineering problems can be approached from multiple directions; thus by being able to work with others, and under the supervision of the classroom-based lecturer, students are able to develop and optimise their approaches to problem-solving by observing their peers. In this regard, viewing others' perspectives on how to apply methods of working and fundamental principles / concepts can be highly beneficial to those who are struggling. Further, when engaged in group activities, students will learn by teaching others (Borglund (2007); Willey and Gardner (2010); Hilsdon (2014)); learning how to explain difficult concepts is a highly valuable skill as it helps students to solidify their understanding and identify gaps in their knowledge that they had not realised.

Courses / modules delivered in a flipped classroom setting also promote formative assessment practices. Black and Wiliam (2009) offers a definition, in stating that: "Practice in a classroom is formative to the extent that evidence about student achievement is elicited, interpreted and used by teachers, learners or their peers, to make decisions about the next steps in instruction that are likely to be better, or better founded, than the decisions they would have taken in the absence of the evidence that was elicited." Further, Black and Wiliam (2009) indicates that, based on a breakdown of formative learning processes split between teachers, peers and learners in Wiliam and Thompson (2007), "formative assessment" may be summarised by five key strategies:

(1) Clarifying and sharing learning intentions and criteria for success
(2) Fostering effective classroom discussions and other learning tasks that elicit evidence of student understanding
(3) Providing feedback that moves learners forward
(4) Motivating students as instructional resources for one another
(5) Activating students as the owners of their own learning

Flipped classroom sessions that promote group problem-solving under the supervision of the lecturer immediately meets strategies 2 through 4 above. The lecturer is able to set problems that encourage effective discussions and steer such deliberations in useful directions as learners see fit. Delivering flipped classroom approaches in the curriculum (say as part of a course or module) also gives the lecturer a significant opportunity to provide high quality, targeted feedback to students while they are dealing directly with problems. Further, not only are these students able to receive high quality feedback from their lecturer who is actively engaged in the class, but this is augmented also from their peers as they discuss and correct each other. Without the need for formally assessing the students, by taking part in problem-solving processes, the lecturer is able to develop an in-depth insight into the students' levels of understanding after each class. This is of significant value from the perspective of formative assessment practices, since it allows the lecturer to make modifications, major or minor, to lesson plans, problem sets and other instructional materials that best benefit the students in upcoming classes.

The structure of the remainder of this paper is now outlined for clarity. The following section describes some of the issues associated with flipped classroom approaches to teaching in the context of addressing points 1 through 5 above. The issues highlighted are specifically related to student home-study. Next, in section 3, two case studies are introduced which describe e-learning projects that address some of the aforementioned issues. Finally, in section 4, elements of the e-learning projects are described in detail with a particular emphasis on how formative assessment practises were addressed.

2. The flipped classroom: a note of caution relating to formative processes

The value that can be gained from using these flipped classroom approaches across and applied to numerous engineering topics is clear; encouraging group collaboration, enhancing problem-solving skills, and providing direct avenues for extensive two-way feedback between the student and lecturer, can all be achieved by freeing up classroom time to concentrate on such activities. During class, students are more likely to be motivated to learn and engage with the material (Strayer (2012); Mattis (2015)), and also to acquire valuable lifelong skills such as tutoring, working as a team and time-management. However, possibilities to seriously engage students in their engineering topic during the home-study component of the flip have to-date been given relatively little attention and are often overlooked (McLaughlin, Griffin, and Esserman (2013); Willey and Gardner (2013)), with a resultant paucity of literature (O'Flaherty and Phillips (2015)), and hence the contribution of this paper to address such neglect. In this regard, it is not difficult to see that simply pushing lectures outside the classroom could have negative consequences. Bergmann and Sams (2012) states that one of the main advantages of flipping the classroom is that students who find it difficult and tedious to concentrate quietly through a standard lecture with no significant engagement then benefit much more from the active learning setting. However, requiring the student to watch the lecture as a video in their own time does not solve these problems. In fact, a standard lecture may have previously included some live student engagement (e.g. electronic surveys, mini problems, simple questions and answers), whereas with a video solution these interactions are diluted or simply unavailable. Further, there is a much larger possibility of a student becoming distracted when watching lectures in their own time. Of course it is possible to implement a framework for verifying whether a student has watched and/or understood the video(s), but this does not automatically mean the student found the experience interesting and engaging.

It is the opinion of the authors that the home-study component of any flip should be given equal, if not more, attention than the timetabled classroom sessions from a curriculum planning perspective. Further, by not giving enough consideration to the home-study component of a flipped classroom aspect of the curriculum (such as in a course or module), a considerable opportunity is then missed, particularly in the context of formative assessment practices. In this regard, this paper explores the possibility of replacing the video lecture approach to the home-study component with web-based interactive-lecture applications. When designing such an e-learning 'tool', instead of approaching every learning objective through the same medium, different combinations of multimedia functions can be packaged together with particular approaches to targeted problems. For example, the best way to explain one concept may be through interacting with a diagrammatic representation of it; then a subsequent concept may be better explained by directly attempting to solve a problem. Audio / visual resources may still be incorporated, but they need not be totally relied upon. Hence, an e-learning tool could be thought of in some sense as an extension of a video lecture, rather than an entirely different approach.

Currently, a number of the authors are preparing a first course module in "advanced stochastic mechanics" at Leibniz University, Hannover, Germany. It will be partially taught in a flipped classroom setting, and thus will draw heavily upon past developments over the last two years made by the authors in the area of web-based interactive-lecture applications. The primary purpose of this paper is to share the lessons that have been learned from the evolution of previous applications, and to do so by providing suggested technical approaches based upon guiding principles of formative assessment. In this way, others seeking to develop their own flipped classroom courses / modules in the field of engineering, especially for the first time, and who do not want to compromise on the taught lecture components, may benefit from the ideas provided herein. In the following section, a brief description of the past applications upon which the authors are basing future development is provided. These make use of animations, short videos, interactive simulations, along with intelligent and routine student feedback. Further, by connecting to a database, an array of rich and granular student feedback may be generated automatically, with this also made instantly available to the lecturer.

3. Interactive app case studies that enhance formative processes

Clearly there are many forms an e-learning application may take, and there may be countless teaching styles that effectively approach any taught subject. This paper is not meant to be seen as a strict guide for creating effective e-learning software, but instead to highlight examples of successful frameworks that align with the aforementioned ideas and objectives. Specifically, elements of two associated e-learning packages are examined, both of which were developed by the authors, for use in distinct applications of engineering teaching in higher education. These particular packages are similar, in that they were designed to be used outside the classroom and to prepare students in advance of upcoming problem classes. They also share similar design features; they are comprised of a number of on-screen tasks that must be completed in a linear fashion (each task leading on to the next). The first application is from an undergraduate course on structural engineering at the University of Liverpool, UK, and was designed to teach the theory of Euler buckling of thin columns (Comerford et al. (2014)). A lot of buckling theory can be taught in a very visual way (i.e. using photos, diagrams and videos), hence it made an ideal candidate for an associated e-learning package. This software was designed as a 'pre-lab' activity, to prepare the students with relevant theory before a practical class. Although not specifically designed for a flipped class, providing background material for home-study in advance of a practical laboratory session is an extremely similar concept. The second application built heavily on the first, and refined certain aspects of the original approaches; most significantly, it included a database-driven "back-end". This particular iteration is from a graduate course on uncertainty and risk in civil infrastructure systems taught at Columbia University, New York, USA. Here, functions were developed that covered material on random variables and processes, with the course being more technical than the first application, and also involving more mathematical content. Despite this, it was still possible to produce an engaging package to cover all of the material, again negating the need for video lectures. In the following, overviews of both applications are given.

3.1. *The University of Liverpool case study: initial developments*

The purpose of this first teaching application was to prepare undergraduate students with important background knowledge before attending a practical laboratory session in which aluminium columns were loaded to the point of buckling. There was no dedicated slot in the curriculum allocated for an additional taught class, and so the students needed to learn the relevant material in their own time. Whilst some might argue that e-learning resources can compete in some cases with face-to-face teaching, it is generally accepted that (at least in the current state of the technology) they do not present an ideal complete replacement for traditional teaching (e.g. Wright (2013); Zhang et al. (2004)). However, where it is impossible to provide timetabled lectures (such as when they have been replaced by 'flipped' problem sessions), the educational advantages in comparison to providing simple streaming videos are numerous (Comerford et al. (2014)). Previous attempts to deal with similar situations through providing video lectures had demonstrated that many students failed to watch the material. Therefore, as an alternative, the authors adopted an interactive software approach, drawing upon evidence of what makes a good lecture with the aim of thus better motivating students to learn in their own time.

It was important that the students engaged with the software and took time to try to properly understand what it was seeking to teach. If a student does not have a core interest in a particular topic, it can often be difficult to keep them absorbed in the subject matter without the pressure of an exam or highly-weighted piece of assessed work. E-learning software gave 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. This requirement for active participation and student interest was a major driving factor in the original design of the application, and led to the development of extensive multimedia features along with highly interactive simulations.

At the University of Liverpool, the students taking the practical laboratory class had a wide array of levels of prior relevant knowledge. This was due to a number of factors, including timetable constraints where particular students would be lectured on relevant base-level theory before the practical laboratory and some afterwards, as well as the diversity in engineering sub-disciplines that the students had been taught to various levels and through different approaches. Given this heterogeneity, it was important that the application would build on students' assorted levels of pre-requisite knowledge and take account of multiple learning styles. One way to do this is through altering the pace and difficulty of the taught material, which in the context of e-learning software draws upon the concept of 'adaptive learning' (e.g. Norton et al. (2013); Waters (2014)). It can be argued (Bergmann and Sams (2012)) that video lectures address this issue (at least that of pace) automatically by allowing students to skip and replay sections; i.e. if a student struggles to keep up with the content in a video lecture, they may then rerun and review segments of the content. However, unless the video has been designed specifically with pausing and replaying in mind, this is likely to become tedious for the learner. 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. Even when formative assessment practices are applied in-class, problems of varying student ability can present themselves. For example, in Roselli and Brophy (2006), the use of infra-red transmitters for students to answer questions anonymously during class provides live and directly relevant feedback to the lecturer. However, it was identified in the paper that time had to be set aside for these tasks and academically-able students were having to wait for others to catch up. In contrast, the e-learning application developed at the University of Liverpool (and discussed in this paper) was purposely designed for students to work at their own pace, as well as to give dynamic feedback and clues for students who appeared to be struggling to then make progress.

3.1.1. Developing formative processes within the software

As highlighted in Section 1, a flipped classroom environment is a great catalyst for formative assessment processes. One of the major factors in delivering formative assessment is the ability to provide feedback to students that specifically enhances their learning processes. This provides a major benefit, allowing them to be able to identify the source of their mistakes and how to rectify them. However, in a flipped classroom setting, students will usually have to wait until the timetabled session to ask questions and receive feedback. Fortunately, it is possible to offer many levels of live dynamic feedback for the student as part of an e-learning software package. Instant feedback comes with the advantage that the problem is fresh in the students' minds and at the time when they are more likely to be interested. It has been observed by the authors that when providing written feedback digitally up to one week after an assignment has been submitted, many students do not even take the time to access it. Further, a significant correlation was observed between students who received low marks and students who did not review their feedback; i.e. the students who were struggling with the work were less likely to be interested in the reasons for this once they had already received their marks. Examples of formative processes within the software are given in section 4.

3.2. *The Columbia University case study: further iterations*

In early 2015, two of the authors worked on another application, to introduce a flipped classroom approach to the initial sessions of a graduate course on uncertainty and risk in civil infrastructure systems at Columbia University in New York. The ideas employed to develop the new software were heavily influenced by the previous application, and so the original buckling software tool was utilised and built upon. Specifically, from the initial project at the University of Liverpool, the authors had at their disposal a framework for producing applications comprised of several small-scale interchangeable sections that required the completion of on-screen tasks to proceed. These tasks made use of a combination of interactive animations, non-interactive animations, multiple choice questions (MCQs), numerical inputs and standard text. This approach was ideal when planning the e-learning material from established lecture notes and lesson plans. Since the software is designed to deliver a 'one-way' learning experience, in the same way as executed by a lecture (from start to finish), a lesson plan could be converted into a blueprint of an e-learning tool with relative ease. Another way to think of this approach would be to consider the tool as a set of interactive lecture slides which the student must progress through by themselves. In this setting, even a lecturer with little experience in programming, software design or technology would in general be able to take a lead role in planning the content, albeit with minimum help of a software developer.

3.2.1. How the framework evolved

Although the authors had the basic framework as a starting point, it was clear from the previous trial at the University of Liverpool that there were some limitations of that approach. The main issue was that no progress monitoring options were initially incorporated into the original system. Progress monitoring was side-lined as summative assessment was never deemed to be a key aim. However, during the first application, there were a number of identified reasons as to why progress monitoring could be advantageous beyond the scope of summative assessment practices. These are listed as follows:

(1) The software could provide dynamic feedback with greater specificity, as the system would have awareness of the students' perceived levels of understanding. In basic

terms, for students who were taking longer and/or clearly struggling with set problems, related exercises could be introduced by the application with the provision of more guidance (e.g. tips / longer explanations / clues).

(2) Further to the previous point, by monitoring progress throughout the application, it is possible not only to build in adaptive feedback for the students, but also to steer them towards completely different presentations of the same source material (either more basic or complex), or even to skip certain material entirely. This is a core feature of an adaptive learning framework, and whilst such an approach can be more time-consuming to implement, it can provide a far more tailored learning experience for the student.

(3) In the original application, there was no means for the laboratory session demonstrator to know how well the students had performed when working through the set tasks (other than a simple way to test if they had completed these). By monitoring and recording student progress through the application, it is possible to equip the demonstrator / lecturer with the ability to adapt problem classes to suit the levels of understanding of their students. This greatly enhances the link between the (student-led) home-study and (lecture-led) in-session taught components of the flipped classroom, since one element is able to directly influence the other.

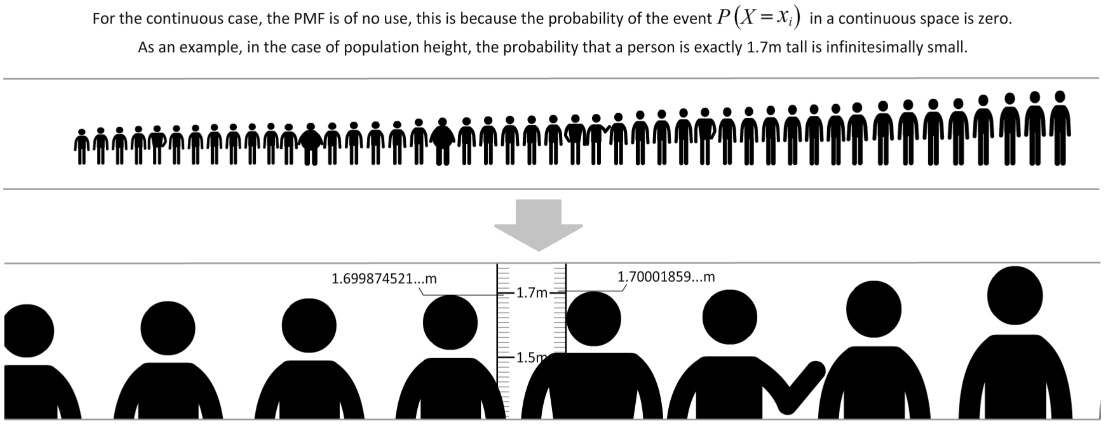
To bring these possibilities into the new Columbia University inspired iteration, a database back-end was developed and connected to the original application framework. This system was able to capture information relating to how long students took to think about questions, how many attempts they made before achieving a correct answer, and also which incorrect answers were provided as inputs.

As a final point, even though summative assessment was not a primary objective, and despite taking a more engaging and dynamic approach to home-study, it seemed likely that given the choice, a number of students would still avoid their set tasks. However, by coupling e-learning software with university student databases, it is relatively simple to verify whether a particular student has completed the task, and to give credits or apply penalties appropriately. In order to alleviate the pressure of real assessment, in both of the highlighted applications (from the University of Liverpool and Columbia University), a mark was simply applied for completing the task with no penalty for incorrect answers. This helped to discourage issues of dishonesty in independent formative assessment (outlined in Gikandi, Morrow, and Davis (2011)) such as those related to cheating, sharing answers for the sole purpose of gaining marks, students completing the tasks on behalf of others, etc.

4. Guiding principles to enhance formative processes in flipped classrooms, with example applications from engineering

This section presents some of the key features of the aforementioned applications that worked well in practice. These features have been identified by the authors as core components that are now being deployed and built upon as part of a third associated application at Leibniz University, Hannover, Germany (previously mentioned), in the area of stochastic mechanics. This paper is thus an opportunity:

- To reflect on what worked well in prior iterations of the approaches advocated by the authors, and to then highlight key principles which are now being taken forward in the new Germany-located application.
- For the authors to share and document their tried-and-tested experiences with others teaching difficult / threshold concepts, and who could benefit from the guiding principles herein.



For the continuous case, the PMF is of no use, this is because the probability of the event $P(X = x_i)$ in a continuous space is zero.

As an example, in the case of population height, the probability that a person is exactly 1.7m tall is infinitesimally small.

Figure 1.: Animation showing large population of people arranged in order of size to demonstrate the concept of a continuous random variable (part of the random variables application)

- To make explicit for other educators seeking to utilise a flipped classroom approach that the home-study component of the flip should be given equal attention, so as to maximise opportunities for formative assessment.

Note that in both example applications (from the UK and USA), students were asked for their opinions to better direct areas of further development. In this regard, the largest sample set of opinion data is from the undergraduate buckling application, which was used in the first semester/term of the academic year. This was completed by over 200 students (i.e. the entire cohort for that module, as confirmed by unique app-completion IDs for each student), and 44 of them provided feedback (which was an optional task). The first thing that is striking is the extent to which the students agreed that they would like to see more similar applications in the future, with a ratio of 43 to 1. In the following, the information gathered from these learners is used, in places, to support the proposed approaches.

4.1. *Embedded multimedia resources*

One of the most basic ways to add content to the application sections is by communicating information through the use of simple visual presentations. For the most part, these areas of exposition can be lifted straight from the existing lesson plan and directly implemented. The user will be presented with on-screen text and accompanying static/animated diagrams; e.g. Figure 1 shows an animation that progresses with the information displayed on the screen. Students may advance through the textual content and diagrams at their own pace. In the same manner, short videos may also be embedded into the e-learning tool. In this regard, although long video lectures may be undesirable for reasons previously discussed, such short and focused video clips followed by questions may be ideal.

If content is not directly available from the lecture slides, numerous open resources can be found on the internet and legally added into software freely. As an example, a similar project entitled “ECorr” (Faidi et al. (2009)), which comprised a series of six open-educational e-learning applications for teaching corrosion, made frequent use of Creative Commons licensed images.

Although there is nothing revolutionary about utilising basic multimedia resources in this setting, it is important to realise that not every single aspect of the application needs to be highly interactive and feedback-enabled. Rather, non-interactive multimedia resources can be used to augment more interesting and dynamic features. For these types of resources, implementation is simple in terms of software development. Further, there will likely be cases where concepts are better taught in a non-interactive manner; this being especially relevant if a lecturer already has targeted and reliable educational materials that they prefer to use.

4.2. *Simple prompt-based learning*

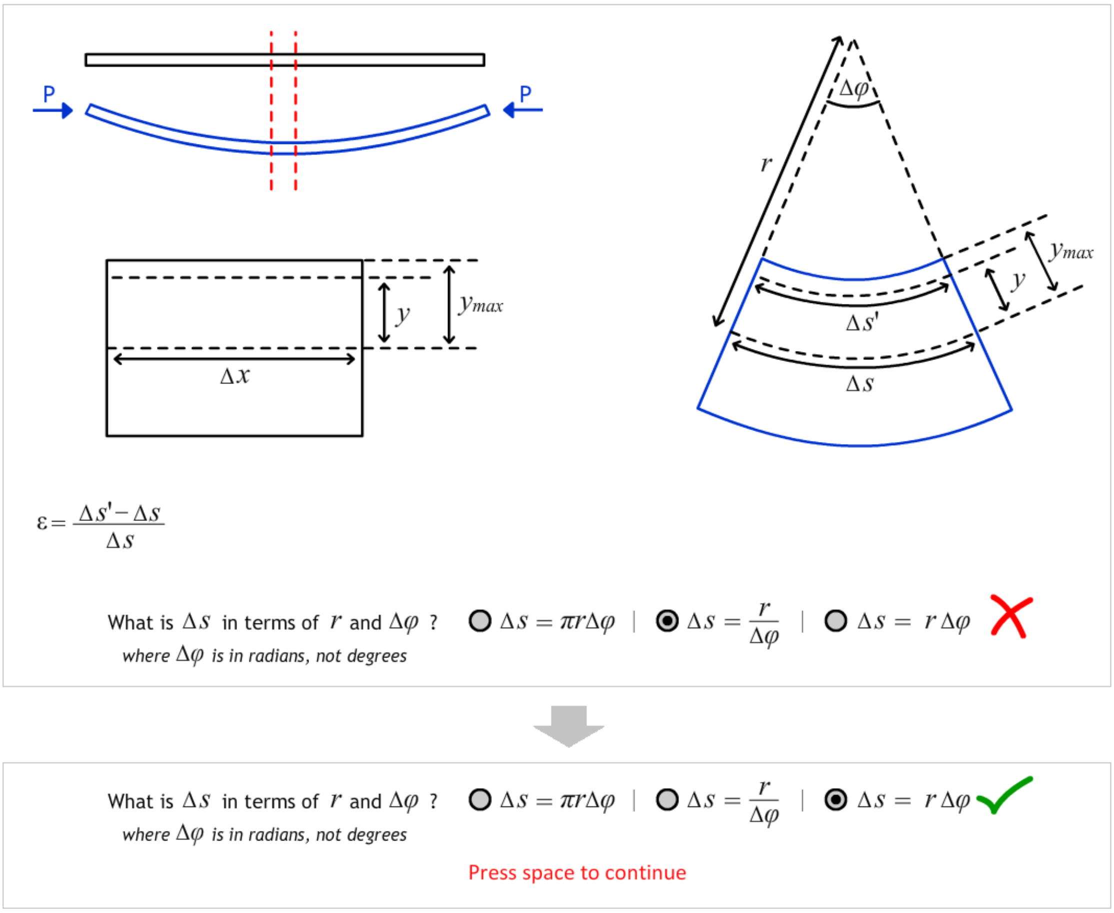
The idea of simple 'prompt-based' learning is common throughout both of the highlighted example applications. It refers to the continuous, high frequency use of MCQs, and is possibly the most integral part of the applications from a learning perspective. The MCQs provide a basic level of engagement with the user, they are the easiest to implement, and can be deployed in a number of innovative ways.

In these applications, users may not advance linearly through the content until they have completed some given tasks on the screen. The most frequent task set is to answer MCQs. These can take the form of radio-button or tick-box questions, where one answer or multiple answers are correct respectively. The implementation is relatively straightforward and consistent throughout: if the user obtains an incorrect answer, they have to try again (e.g. Figure 2 (top)); but with a correct answer, they are allowed to progress (e.g. Figure 2 (bottom)).

The MCQs are not designed to be used as an assessment method in these cases. Instead, the students are supposed to be learning from the set application activities and not assessed; and as such they should not feel there is any penalty for getting incorrect answers. Under these conditions, MCQs can be applied for teaching rather than directly assessing. Two specific examples are highlighted:

(1) MCQs may be used merely to keep the user engaged with the content on the screen. The concept is very straightforward and does not really add depth or pedagogical value; however, the authors felt that the approach was highly effective for its purpose, and so it is mentioned here. When working from home, in reviewing lecture slides, notes or videos for which there is no interaction, if a student is not particularly interested in the subject matter, they may not absorb the information efficiently, or indeed at all. By prompting the user for input, based on the current content on the screen, they are immediately required to focus. Designing these types of questions is actually incredibly uncomplicated as they do not need to be specifically related to the core learning outcomes. All that is needed is only to ensure that the user has read and understood everything on the screen (i.e. even if the user is tired or bored, they must concentrate to some extent to make progress). An example is shown in Figure 3, in which the user is asked how a geared mechanism actually functions. This is not required knowledge for the subject, but answering correctly confirms that the diagram provided for the learner has been properly studied.

(2) Since the example applications herein do not penalise the students for incorrect answers (apart from stifling progress through the content), MCQs provide an alternative thought-provoking method of expressing a concept of knowledge. When a fact needs to be stated, rather than simply providing the information, the student may be asked a question to which the correct answer is that fact. Hence, incorrect answers are encouraged and become part of the learning process. In this way, by using relatively large numbers of questions that present material in a granular manner, when students answer them incorrectly they should then be able to spot their mistake without the need for additional feedback. This is especially useful when dealing with mathematical concepts (as discussed shortly). Further, for difficult / threshold problems, incorrect answers may still be coupled with appropriate feedback (as shown in



$\varepsilon = \frac{\Delta s' - \Delta s}{\Delta s}$

What is Δs in terms of r and $\Delta\varphi$? ○ $\Delta s = \pi r \Delta\varphi$ | ● $\Delta s = \frac{r}{\Delta\varphi}$ | ○ $\Delta s = r\Delta\varphi$ ✗

where $\Delta\varphi$ is in radians, not degrees

What is Δs in terms of r and $\Delta\varphi$? ○ $\Delta s = \pi r \Delta\varphi$ | ○ $\Delta s = \frac{r}{\Delta\varphi}$ | ● $\Delta s = r\Delta\varphi$ ✓

where $\Delta\varphi$ is in radians, not degrees

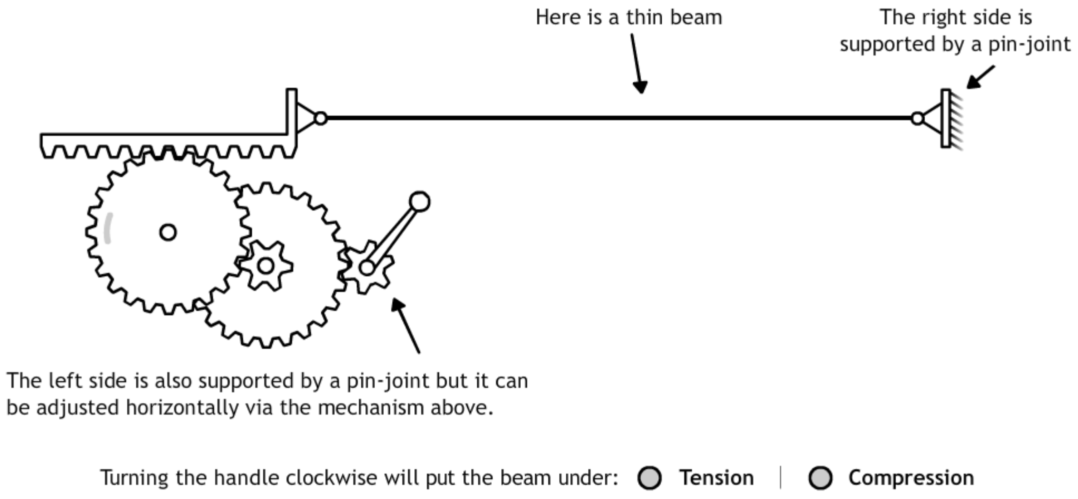
Press space to continue

Figure 2.: An incorrect MCQ prompts the user to try again without any penalty (top); a correct MCQ allows the user to progress further in the package (bottom) (part of the buckling application)

Section 4.4).

4.2.1. Granular MCQ-based mathematical derivations

One particularly useful way in which MCQs can be utilised, fitting with example (2) of the previous section, is to present and explain equations. Engineering students are typically taught how to apply equations, learn why they work and to various degrees of depth, how they are derived. Application and derivation of equations are often taught by demonstrating solutions to example problems, both in books and lectures. In some lectures, the students may be encouraged to follow along or be given time to solve small problems themselves. Unlike a text book or lecture however, by using MCQs in an e-learning application, it is possible to guide the students through mathematical derivations and applications whilst testing their understanding at each step. In the example applications communicated throughout this paper, equations are presented in very small steps, some of which would be considered too minor, and with knowledge already assumed, in relevant text books. This high level of granularity is also infeasible in a taught-lecture setting because of time constraints. In this way, the student is being guided through solving example problems themselves that they can follow along at their own pace, instead of feeling they are operating slowly and being left behind, or waiting for others to catch up. An example of this granular, worked-problem approach can be seen in Figure



Turning the handle clockwise will put the beam under: ○ **Tension** | ○ **Compression**

Figure 3.: An MCQ that is not specifically related to the learning objectives is utilised to ensure that the student has studied a diagram of buckling test equipment, which will later form an element of an interactive simulation (part of the buckling application)

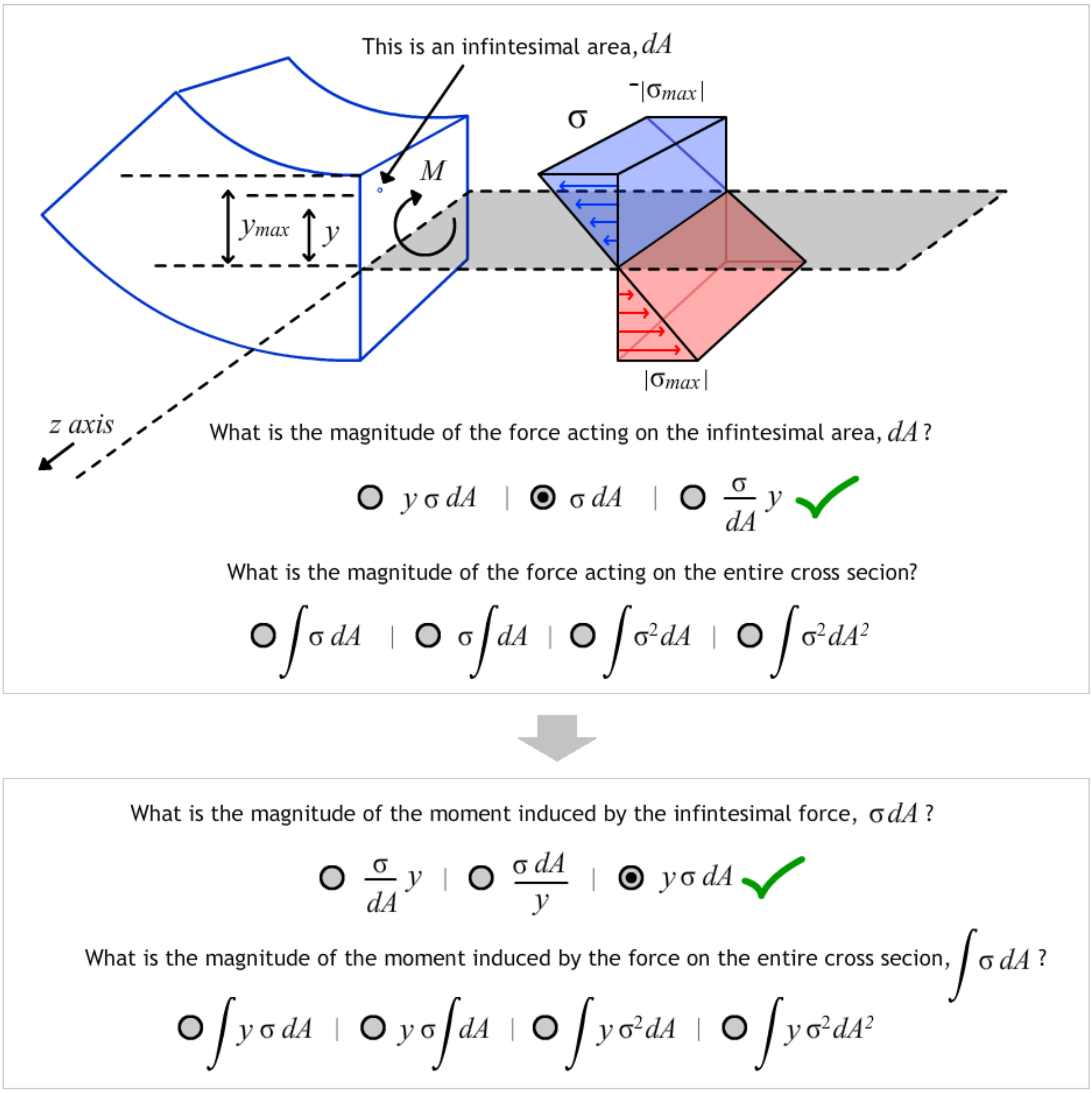
4, where four MCQs were used to build up to the equation, in this case for the moment over the cross-sectional area of a buckled member. The idea is that wherever possible, only the most basic assumptions on user understanding were made. In a text book example of Figure 4, the equation for moment magnitude across the cross section would likely be simply stated as $\int y\sigma dA$. Instead, this equation is built up in pieces; referring still to Figure 4, starting with the concept of stress, the integral is introduced. From the first two questions shown, the student can grasp the physical meaning of the integral independently. Then in the third question, the concept of moment is tested. Finally, in the fourth question, these two concepts are joined together.

This mathematical MCQ concept can also be taken one step further and set within an adaptive learning framework. For example, by providing the student with the fourth question in Figure 4, they have the option of skipping the first three (by getting the correct answer first time). However, one single incorrect attempt ‘unlocks’ the initial three questions, ultimately guiding the student to the correct answer.

This approach to presenting mathematical content proved to be highly popular with the students. In the case of the buckling application, almost 90% of the undergraduate students said they were able to follow the majority of the derivations. It is important to note that the level of mathematics became quite advanced for many of these students, particularly for the derivation of the Euler buckling equations, where they were in very unfamiliar territory. Further, the written feedback echoed these statistics; one student commented: *“I appreciated the way that it [the interactive home-study e-learning] broke the derivations down into easy to follow steps”*, and another: *“I particularly liked how it explained things step-by-step at my own pace, something that lectures nor revision from lecture slides can achieve”*.

4.3. *Interactive diagrams and simulations*

In this section, the uses of dynamic graphics that respond to learner input are discussed. In the example applications (previously developed in the UK and USA), interactive on-screen tasks take many forms, ranging from relatively simple extensions of MCQs to



What is the magnitude of the force acting on the infintesimal area, dA?

○ $y\,\sigma\,dA$ | ● $\sigma\,dA$ | ○ $\frac{\sigma}{dA}\,y$ ✓

What is the magnitude of the force acting on the entire cross secion?

○ $\int \sigma\,dA$ | ○ $\sigma \int dA$ | ○ $\int \sigma^2 dA$ | ○ $\int \sigma^2 dA^2$

What is the magnitude of the moment induced by the infintesimal force, $\sigma\,dA$?

○ $\frac{\sigma}{dA}\,y$ | ○ $\frac{\sigma\,dA}{y}$ | ● $y\,\sigma\,dA$ ✓

What is the magnitude of the moment induced by the force on the entire cross secion, $\int \sigma\,dA$?

○ $\int y\,\sigma\,dA$ | ○ $y\,\sigma \int dA$ | ○ $\int y\,\sigma^2 dA$ | ○ $\int y\,\sigma^2 dA^2$

Figure 4.: MCQs building expression for force over a member cross-section (top), and then for moment over the cross-section (bottom) (part of the buckling application)

complex stylised visual simulations. In Figure 5, one such extension of a MCQ is shown; where the learner must plot points on a graph by clicking within a grid. The activity is utilised within the application in the same way as the other MCQs (i.e. the user must select the correct points before they can proceed). Alternatively, a more complex example is shown in Figure 6. Here, the learner is faced with an interactive plot, where they can alter properties of a bi-variate probability density function using sliding scales along with click-and-drag integral boundaries. In this case, the user's task is not to select a correct answer within the dynamic graphic, but instead to use it to find answers to separate questions (i.e. MCQs, or in this case numerical inputs as shown). Hence, although Figure 6 is more complex, it can be re-used several times as a subject in a larger set of lecturer-defined questions. Understandably, implementing such components can be time-consuming. This is not only due to increased programming complexity, but also because the design phase is more demanding; since the user experience must be considered from both design interface and learning perspectives. However, these types of activities tended to elicit the most positive responses from students when asked about

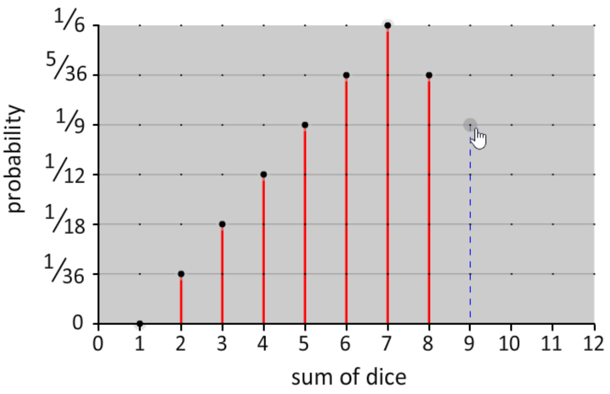
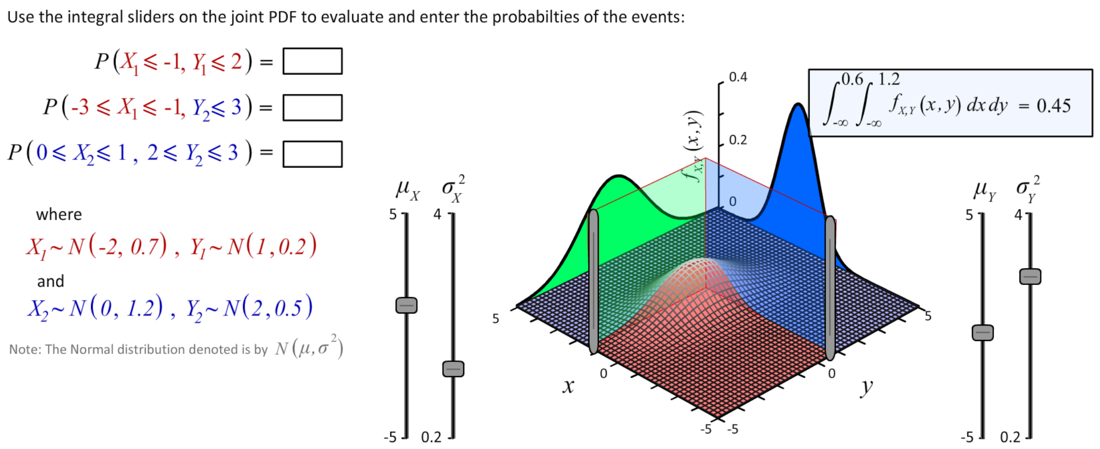


Figure 5.: Simple interactive graph taking the form of an extended MCQ for plotting the probability mass function of two dice (part of the random variables application)



Use the integral sliders on the joint PDF to evaluate and enter the probabilties of the events:

$P(X_1 \leqslant -1, Y_1 \leqslant 2) =$ ☐

$P(-3 \leqslant X_1 \leqslant -1, Y_2 \leqslant 3) =$ ☐

$P(0 \leqslant X_2 \leqslant 1 , 2 \leqslant Y_2 \leqslant 3) =$ ☐

where

$X_1 \sim N(-2, 0.7) , Y_1 \sim N(1, 0.2)$

and

$X_2 \sim N(0, 1.2) , Y_2 \sim N(2, 0.5)$

Note: The Normal distribution denoted is by $N(\mu, \sigma^2)$

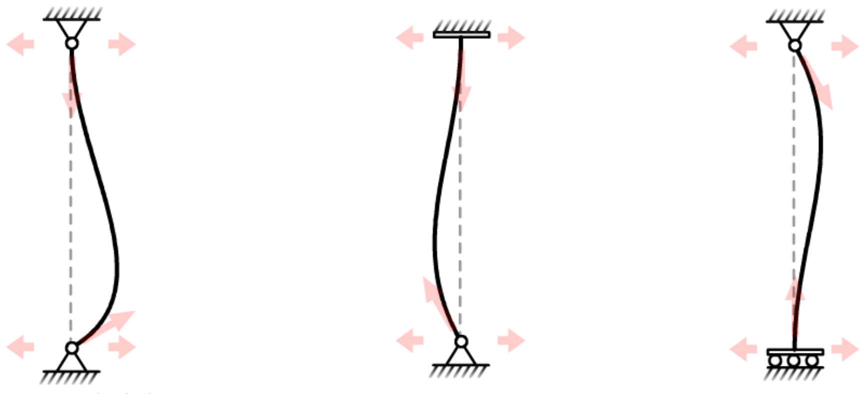
$\int_{-\infty}^{0.6}\int_{-\infty}^{1.2} f_{X,Y}(x,y)\,dx\,dy = 0.45$

Figure 6.: Complex simulation to be used exploratively (right), and for use in answering separate questions within the application (left) (part of the random variables application)

their experiences with the application software; for example, in relation to a buckling simulation introduced in Figure 3, comments in the class were very favourable, with students saying that engaging with it was “enjoyable” and “didn’t really feel like work”.

4.4. *Additional feedback for the student*

In all cases where interactive features are used, some level of feedback is available to the students. Being informed instantly of an incorrectly answered MCQ is a form of feedback in itself, and can often be informative without additional feedback when the MCQ steps are granular (unlike an assessment question, which is more likely to require additional explanation as to why given answers were incorrect). Further, dynamic diagrams and simulations can offer explorative environments in which the student receives graphical feedback. However, it is not difficult to include additional written feedback to the students in an e-learning setting for which the lecturer feels more explanation is needed. Feedback can be given dynamically based upon how the student made an incorrect input. Figure 7 gives an example (from the University of Liverpool initiated application) of a dynamic graphic in which the student is asked to arrange the buckled column shapes. The text



Pinned joints cannot support moments, therefore the direction of the beam will likely change at this point.

These beams are assumed to be homogeneous (Young's modulus and second moment of area remain constant throughout), therefore, because the end conditions are identical, the deflected shape will likely be symmetrical.

This is a fixed joint on a lateral roller, it cannot support horizontal forces, therefore it will likely move sideways.

Figure 7.: Dynamic feedback displayed when an interactive buckling of struts task has been completed incorrectly (part of the buckling application)

Remove the load first!

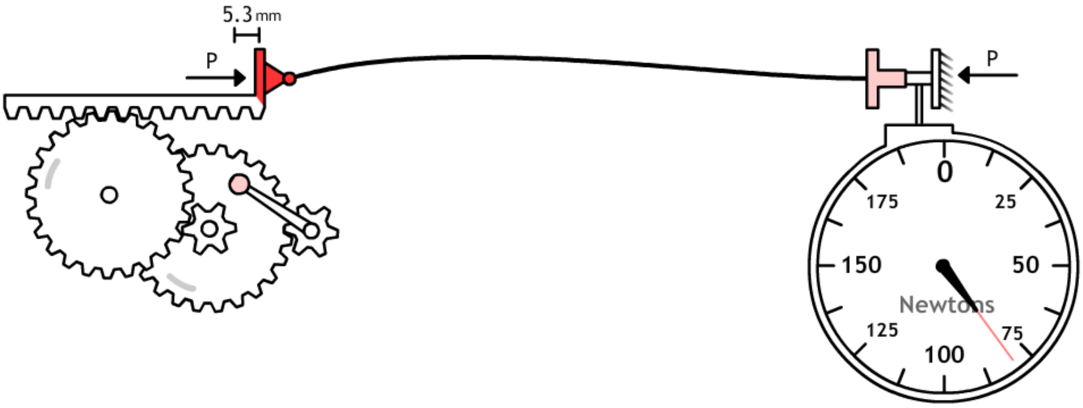


Figure 8.: Advancement of the diagram shown in Figure 3 in which the user is given feedback on how to interact with the simulation (part of the buckling application)

feedback is generated based specifically on why the student has been incorrect in their understanding, and guides them towards the correct answer. Another example (from the same application) is shown in Figure 8, where the user is unable to change the parameters of an interactive experiment, and is provided with relevant feedback (where in this case the purpose is to simulate properties of a real buckling experiment).

It is important to note that dynamic feedback becomes more significant when utilising interactive simulations (as described in the previous section) where students may get stuck and not be able to continue. A similar project to provide an e-learning tool for independent home study of free body diagrams which provided live feedback is discussed in detail in Roselli et al. (2003); although the software was very well received by the students, they criticised the feedback for being too generic and not pointing them towards solutions. Hence, the value of predicting common mistakes and misconceptions of students when answering these questions, and providing specific and targeted feedback when they are input should not be underestimated. Further, to prevent students from becoming stuck who are experiencing unforeseen difficulties, a series of generic hints can still be given, and finally (after a given amount of time) the answer may be offered. Enhancing the e-learning software to account for previously unforeseen student difficulties is a further possibility when a database is used to store user statistics; i.e. the lecturer or developer of the application is able to identify such problems, and then add to the array of dynamic feedback for future users.

4.5. *A note on the technical development of the e-learning tools*

Providing a complete and detailed breakdown of the development of such web-based interactive tools (from a technical rather than educational standpoint) is out of the scope of this paper. There are a vast array of development options available with both free and commercial licences. The e-learning tools detailed herein were originally developed in Adobe Animate, using Adobe's Actionscript3 object oriented programming language. However, the latest project by the authors, under development at Leibniz University, Hannover, is based upon Javascript and makes use of modern HTML5 web technologies. Developing in this way requires a significant amount of programming time and, whilst it allows for a high level of control and customization (especially when creating interactive simulation elements), it may not be the most efficient solution in all cases. In this regard, it is important to mention that there are a number of tools specifically designed for authoring e-learning content with user-friendly frameworks. These tools tend to rely primarily on specific types of pre-set user interaction (such as MCQs), and allow for such content to be produced quickly, and without the need for writing code.

5. Conclusions

This paper makes a unique contribution to the growing body of literature surrounding flipped classroom approaches to engineering courses, by giving herein greater consideration to an often overlooked but vitally important component of this educational approach, namely the home-study lecture material. In this regard, by replacing video lectures (i.e. the traditional means) with interactive applications (i.e. the innovative ways developed by the authors), it is shown that formative assessment practices that are inherent to the taught element of the flipped classroom can be better integrated into the independent student learning component.

To support the highlighted benefits of interactive e-learning over video lectures in a flipped classroom setting, detailed examples are provided from two successful software applications that each accentuate formative assessment and feedback processes in engineering; which were each developed specifically for their respective courses and administered to the students as home-study tasks. These example applications support a set of guiding principles to software development for this purpose of ensuring formative processes, and it is the authors' intention that others seeking to introduce or further develop flipped classroom teaching are able to benefit from these approaches. Specifically, alternative uses of MCQs, the presentation of mathematical derivations, along with the need to deliver dynamic and adaptive feedback, as well as the overall application framework and its implementation, are all described in this paper, with the explicit aim of providing a starting-point for related developments in other courses.

It is recognised though that implementation of the ideas presented herein is not without challenges. Lecturers have their own methods of teaching that they are comfortable with, and so in the case where video lectures are used in a flipped classroom setting, it is likely that the lecturer responsible for the module / course will produce those videos. Unfortunately, development of highly effective interactive e-learning packages invariably necessitates more work for the educator, and this, coupled with a potential software development learning curve, could render a direct approach in this way potentially taxing. In this regard, as a future addition to the educational aspects articulated throughout this paper, the authors are producing a complementary article to communicate a more low-level technical breakdown of the processes involved in creating such an application package, and to also highlight the advantages and limitations to utilising third-party educational software 'builders' that may streamline and simplify those processes.

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