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Improving learning through technology-enhanced dynamic and interactive engineering content

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ABSTRACT

CONTEXT
The rise of flexible degree structures has allowed students to explore a wider breadth of knowledge. This has resulted in an increase in students with diverse backgrounds in different areas of foundational mathematics and physics enrolling in engineering subjects. Teaching engineering concepts while catering to these diverse cohorts is an ongoing challenge. This is compounded by the fact that teaching activities still largely rely on static two-dimensional formats such as PowerPoint slides and handwritten notes. The engineering concepts on which this study is based are those involving spatially and temporally varying elements.

PURPOSE OR GOAL
To improve learning outcomes and the student experience, we explored the integration of new technologies in the development of more effective supplementary teaching and learning materials. We were particularly interested in technologies allowing dynamic phenomena to be fully explored and interrogated by students. The long-term goal is to develop a library of interconnected interactive resources that students can access to fix any gaps in expected knowledge, and to reinforce concepts taught in synchronous learning sessions (i.e. lectures, tutorials) by providing alternative and more visual perspectives.

APPROACH OR METHODOLOGY/METHODS
Applying a design-based research methodology, we initially experimented with the introduction of a series of short concept-focused video tutorials in a second-year engineering mechanics subject. Following positive student feedback, we broadened the scope of this project to include a graduate-level medical imaging subject. In this next iteration, the H5P platform was used to embed interactive quizzes within the videos, which students could use to gauge their understanding and receive real-time feedback. An interactive MATLAB-based virtual lab prototype – simulating a mechanical testing lab – was also developed.

ACTUAL OR ANTICIPATED OUTCOMES
Survey data indicated that students find interactive embedded quizzes helpful in their learning – this was the case for incorporation in both our short concept videos and pre-recorded lecture content. Conversely, students found the current iteration of the virtual lab neither helpful nor unhelpful in their learning.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY
While more work remains to be done in this space, our findings suggest that access to more visual, dynamic, and interactive content allows students to explore engineering concepts in more intuitive ways than is possible with traditional two-dimensional formats.

KEYWORDS
Technology-enhanced, h5p, simulation

Introduction

Flexible degree structures such as the Melbourne Model at the University of Melbourne have allowed students to focus their studies in a specific subject area while still exploring a wider breadth of knowledge. This has resulted in an increase in the diversity of students enrolling in engineering subjects, in terms of their depth of background knowledge in mathematics and physics. Catering to this diversity has been challenging, as the cohort is unevenly prepared to tackle the specific challenges of learning new engineering concepts, many of which involve motion, time dependence, and vectors. Teaching these concepts comes with its own set of challenges, as this is still predominantly done using static PowerPoint slides or handwritten notes. Again, as many of these concepts involve spatially and temporally varying elements, the incongruence between delivery using static media of concepts involving dynamic phenomena is especially noticeable. While there are workshops and labs offered for hands-on experimentation, these typically allow for only a small subset of concepts to be explored.

To address the issues above, we investigated the integration of new technologies in the development of more effective teaching and learning materials. We were particularly interested in enhancing existing content with technologies that would allow students to properly explore and interrogate complex phenomena involving motion. Our overarching goal was to develop a library of interactive resources that students would be able to access via the Learning Management System to patch any gaps in expected prior knowledge, or to further reinforce concepts covered in lectures by providing different and more visual and dynamic perspectives.

This paper describes the application of a design-based research (DBR) methodology in the development of technology-enhanced dynamic and interactive engineering content to support the learning of engineering concepts in subjects taught in the Faculty of Engineering and Information Technology at the University of Melbourne.

Approach

A design-based research (DBR) approach was adopted in the development of these new teaching and learning resources. The DBR methodology is characterised by “continuous cycles of design, enactment, analysis, and redesign” (The Design-Based Research Collective, 2003). Scott, Wenderoth, and Doherty (2020) further describe DBR as an iterative process with the following four steps: the identification of problems or challenges, the design of potential solutions, the evaluation of those solutions, and finally, a reflection on those solutions and their implementation. This section describes the two DBR iterations that have occurred to date with reference to these four steps.

First DBR Iteration

Identification

The diversity in foundational physics and mathematics background was first identified as a problem in the subject Engineering Mechanics (ENGR20004). This subject is offered year-round (Semester 1, Semester 2, Summer Semester), with average enrolment of >500 students per year. As a fundamental undergraduate-level engineering subject, it forms the basis for further engineering studies within the following disciplines: biomedical, civil, environmental, mechatronics, mechanical, and structural. In the subject, students are introduced to translational and rotational motions that result in a body subjected to different forces. Upon completing the subject, students are expected to be able to confidently describe and analyse the motion of particles and rigid bodies using two-dimensional vectors. In addition to the challenge of effectively delivering concepts involving dynamic two-dimensional motion while catering to the varied educational backgrounds of the cohort, a major challenge in this subject has also been to maintain high levels of student engagement.

Design

Multiple studies have shown that videos can be an extremely effective tool in helping students learn (e.g., Rajadell and Garriga-Garzón, 2017). In this context, a dynamic format such as video is essential in teaching concepts that are difficult to visualise with traditional static formats (Dash et al., 2016), such as those involving two-dimensional motion. In line with this, we developed a series of 34 video tutorials to address the previously described problems in ENGR20004. These covered a range of fundamental concepts aligned with what was considered prerequisite knowledge to succeed in the subject. In designing these videos, recommendations previously described by Brame (2016) were followed. These recommendations are divided into three categories based on the elements being considered: cognitive load, student engagement, and active learning.

To enhance germane load (cognitive activity directed towards achieving intended learning outcomes) and reduce extraneous load (cognitive activity that does not help the learner towards intended learning outcomes), text was avoided beyond the use of necessary key words for signalling purposes, and the use of music and complex visual backgrounds was minimised. In addition to this, many of these videos also featured narrated animations, an example of matched auditory and visual modalities that has been shown to optimise cognitive load. To maximise student engagement, all videos were kept short (3-5 minutes in duration), meaning that some of the more complex concepts had to be segmented into multiple shorter videos. Conversational, enthusiastic language was used to foster a sense of connection between the viewer and the instructor, and links to in-lecture material and real-world engineering applications were frequently stressed. To promote active learning, guiding questions were inserted at logical points within each video. One of the later videos in the series covered the concept of free vibration and was accompanied by a simple MATLAB-based interactive interface within which students could alter parameters and observe the resultant motion of a spring-block system.

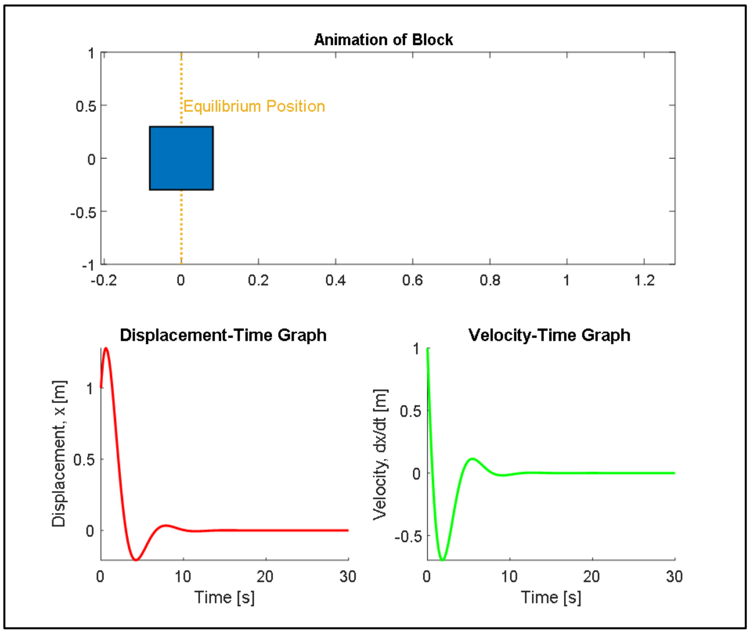

Figure 1: Output of MATLAB-based interactive interface covering the concept of free vibration.

Evaluation

In this first iteration of the DBR process, no evaluation in the form of a formal student survey was conducted on the produced materials. However, the videos were well-received: the 34 available videos registered an average view count of 793 each (averaging to 2.58 views for each of the 307 students enrolled that semester). In an informal poll conducted within lectures midway through the semester, of the 51% of the students who had indicated that they had actively engaged with the material, 99% rated the material as being helpful in their learning.

Reflection

Reflecting on this initial implementation, we identified the following as items to address in the second DBR iteration:

- Adding a second, graduate-level candidate subject within which to pilot our developed resources (to ensure representation from both undergraduate and graduate-level students),
- Including more interactive elements to further promote active learning and engagement (in line with the MATLAB-based interactive interface accompanying the video on free vibration),
- Setting up a formal method of evaluating our implementations, beyond simply relying on view counts and informal polling.

Second DBR Iteration

Identification

Medical Imaging (BMEN90021) was identified as a second subject for the study based on ease of access: two of the authors are associated teaching staff. This subject is offered only in Semester 1, with average enrolment of about 60 students per year. It is a graduate-level biomedical engineering elective that introduces students to the physics, engineering, and physiology of medical imaging. It relies on knowledge of various physics concepts including electromagnetism, nuclear and radiation physics, acoustic physics, as well as mathematics of signal and image processing. As such, the major challenges in this subject are similar to that of ENGR20004: it requires solid – and in this case, interdisciplinary – foundational knowledge, and the concepts covered are dynamic in nature.

Design

Following further recommendations described by Brame (2016), all existing and new video tutorials were embedded with interactive quizzes using H5P (Figure 2). H5P is an HTML5-based tool that allows the creation of rich, interactive content and activities that can be embedded seamlessly into online learning materials. The rationale behind this integration was to promote active learning: students are forced to recall – as opposed to just receive – information. Furthermore, it allows students to gauge how well they understand the material in real-time, allowing them to more quickly identify concepts that require revision. Some lecture content was also shifted to pre-recorded video formats, and some of these lecture videos were similarly modified to feature embedded quizzes.

The idea of promoting active learning and engagement via the further development of interactive physics-based simulations was expanded, and the creation of a virtual lab was proposed. This was initially envisioned as a repository of virtual physics sandboxes within which students might perform parametric investigations and develop their engineering intuition (Dalgarno et al., 2009). For example, one might imagine students having access to a virtual materials testing machine after first attending an existing hands-on counterpart laboratory session. In such a simulation, students are free to simulate mechanical tests on various materials and to measure and explore the relationships between engineering quantities such as stress, strain, and Young's modulus. Unlike physical campus-based labs which are time-limited, students are able to remotely access this virtual lab anytime, anywhere. Additionally, students might be able to investigate scenarios that are prohibitively expensive or too dangerous in real life (Heradio et al., 2016).

In this second DBR iteration, we proposed that a virtual lab prototype first be developed based on an existing campus-based practical on materials testing. In designing this prototype, the specifications were that its interface be kept simple, with students requiring no prior programming experience to operate within it. All aspects of the simulation should be easy to control using simple virtual levers, drop-down boxes, drag-and-drop objects, numerical entry textboxes, or similar elements. Based on these specifications, a functional materials testing virtual lab prototype was developed using MATLAB App Designer and was deployed in ENGR20004 (Figure 3).

Figure 2: Example of interactive video with embedded questions.

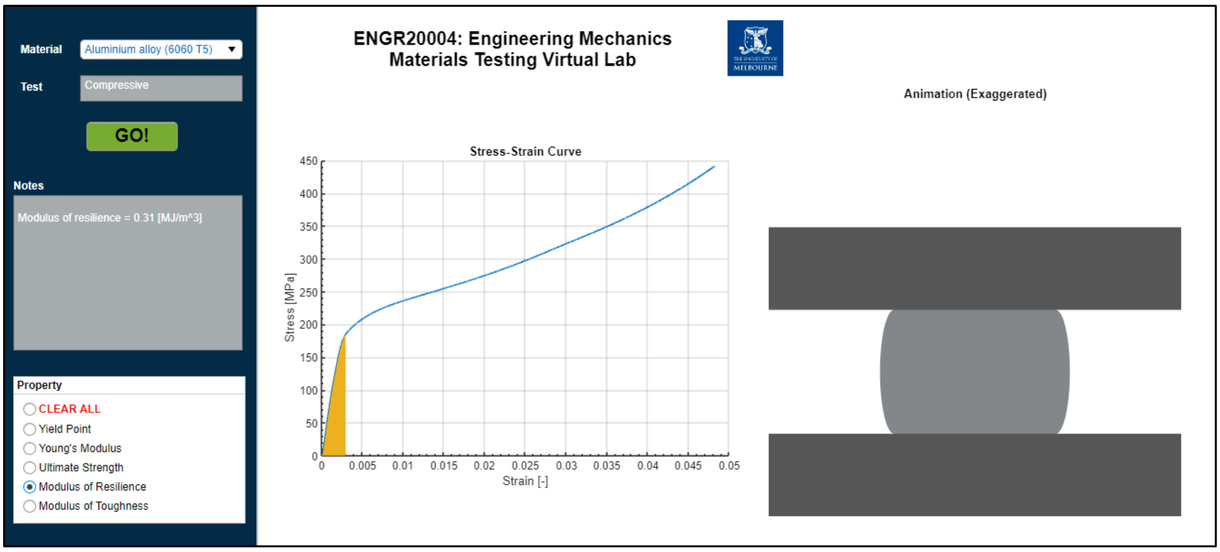

Figure 3: Materials testing virtual lab prototype developed for deployment in ENGR20004.

Evaluation

To evaluate the resources designed in this second DBR iteration, formal Qualtrics-based student surveys were conducted anonymously within both ENGR20004 and BMEN90021. For both subjects, an opt-out strategy with implied consent was used to gather data from all enrolled students. For ENGR20004, participants scored the following resources (asterisks indicate resources developed as part of this study) on a 5-point Likert scale (1: Did not use, 2: Not helpful, 3: Neither helpful nor unhelpful, 4: Moderately helpful, 5: Extremely helpful):

- Lecture videos with embedded quizzes
- Lecture videos without embedded quizzes*
- Weekly on-campus/online tutorials
- Worked example online lectures
- Concept videos with embedded quizzes*
- Concept videos without embedded quizzes*
- Lecture reading/book references
- Group assignments and laboratories
- Materials testing virtual lab*
- Other

We were particularly interested in comparing how students perceived the helpfulness of similarly formatted content with versus without embedded quizzes (i.e. lecture videos with/without embedded quizzes, and concept videos with/without embedded quizzes). Focusing on content with embedded videos, we were also interested in detecting any differences in student perception of content delivered via lecture videos versus concept videos.

For BMEN90021, participants scored the following resources using an identical 5-point Likert scale (asterisks indicate resources developed as part of this study):

- Lectures
- In-lecture tutorials
- Site visits
- Concept videos with embedded quizzes*
- Workshops
- Workshop reports
- Other

Outcomes & Discussion

Survey results for ENGR20004 are shown in Table 1. Due to low response rates (n=5 for all questions), the results for BMEN90021 have not been reported here. A visual representation of the data for ENGR20004 is provided in Figure 4.

Focusing on ENGR20004, we found that content (both lecture and concept videos) with embedded quizzes was rated as being statistically significantly more useful than content without (Wilcoxon rank sum test: $p<0.001$ for lecture videos, $p=0.006$ for concept videos). For content with embedded quizzes, no statistically significant differences were detected between lecture videos and concept videos ($p=0.4098$). These results suggest that interactive quizzes embedded with H5P are perceived by students as being more helpful in their learning, possibly by promoting engagement and active learning. More data will have to be collected to investigate definitive links between this and student performance.

The survey results indicated that students found the materials testing virtual lab less helpful. This resource had a mean rating of 3.05, considerably lower than that received by the resource “group assignments and laboratories” (3.85). While more detailed student feedback on how to improve this specific resource was not collected here, we propose the following interventions for the next DBR iteration:

- The materials testing virtual lab was a prototype and served as a proof-of-concept, involving an almost exact simulation of an existing physical laboratory-based activity. As a result, students who had already completed and understood the actual laboratory-based activity might not have found the virtual lab useful for further exploration. Future iterations on this resource should focus on incorporating experimental conditions not feasibly measurable within the physical laboratory, increasing their value.
- Gamification has previously been reported to result in increased student engagement and enhanced learning (Coller and Scott, 2009). Future iterations on this resource should explore the incorporation of more interactive and game-like elements to increase student engagement. These might take the form of accompanying quizzes, or the incorporation of virtual lab resources in design-based activities.

Table 1: Survey results for ENGR20004 resources.

Resource	Did not use (1)	Not helpful (2)	Neither helpful nor unhelpful (3)	Moderately helpful (4)	Extremely helpful (5)	n	Mean	Standard Deviation
Lecture videos with embedded quizzes	1	10	8	16	16	51	3.71	1.16
Lecture videos without embedded quizzes	1	14	15	14	1	45	3	0.89
Weekly on-campus/online tutorials	0	4	7	17	28	56	4.23	0.93
Worked example online lectures	8	8	13	25	25	79	3.65	1.29
Concept videos with embedded quizzes	8	7	10	31	20	76	3.63	1.25
Concept videos without embedded quizzes	9	6	28	23	9	75	3.23	1.14
Lecture reading/book references	10	10	17	23	14	74	3.28	1.29
Group assignments and laboratories	1	10	8	35	20	74	3.85	1.01
Virtual materials testing lab	16	9	20	21	12	78	3.05	1.35
Other	18	3	22	8	4	55	2.58	1.27

The evaluation step in this second DBR iteration has allowed for the usefulness of these technology-enhanced and interactive resources to be quantified. However, evaluation strategies within the next DBR cycle should focus on collecting student feedback on specific ways through which these resources might be improved to aid in their learning. Methods of increasing response rates, particularly for BMEN90021, should also be explored and implemented.

Lastly, we note the bulk of this technology-enhanced content was developed prior to the ongoing coronavirus pandemic. It was therefore designed to be supplemental in nature, with students completing most of their learning through traditional means such as on-campus lectures. With the rapid shift towards blended (simultaneous on-campus and online) delivery in tertiary education, the lessons learned in developing this content should be harnessed to develop primary teaching and learning materials that are more engaging and effective in such settings.

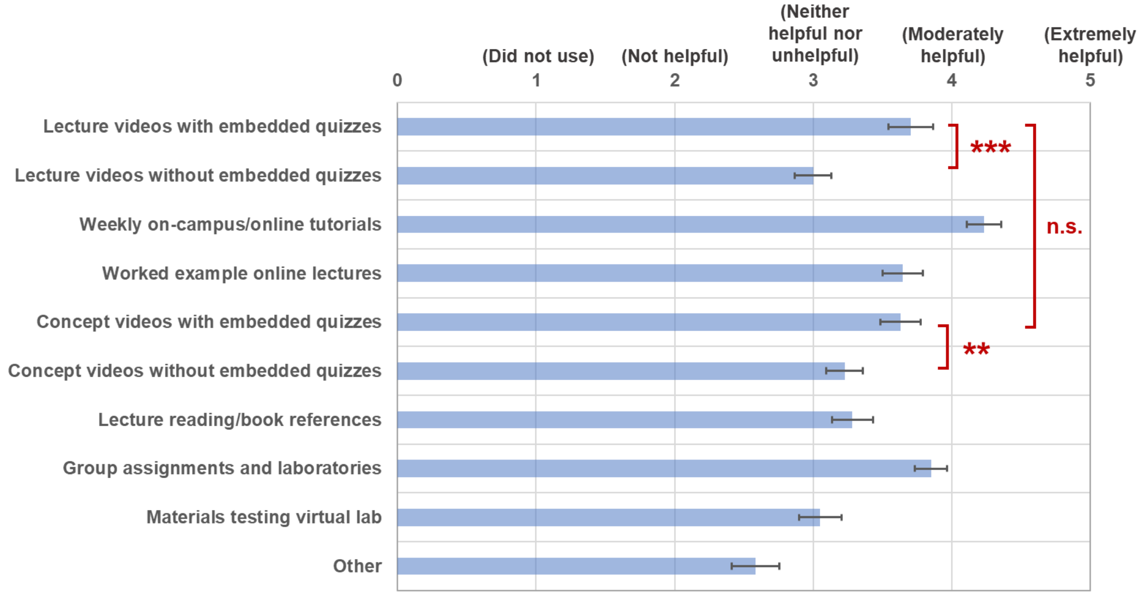

Figure 4: Visualisation of survey results for ENGR20004 resources (: p<0.01, ***: p<0.001, n.s.: not significant)**

Conclusion

A flexible degree structure has resulted our students enrolling in engineering subjects with diverse levels of foundational physics and mathematics knowledge. To address this issue, we applied a design-based research methodology to develop technology-enhanced and interactive content to improve student learning. Two iterations of this approach have been conducted to date, with the main resources developed being concept videos with embedded quizzes and a virtual lab prototype revolving around materials testing. Survey results indicate that students rate videos featuring quizzes embedded with H5P as being helpful in their learning. However, students did not find the current iteration of the virtual lab as useful as existing physical laboratory-based activities. As part of the reflection step of the design-based research cycle, several suggestions were proposed to improve these resources in the next iteration. We also note that these findings might assist in the creation of more effective primary teaching and learning materials in the shift towards blended learning.

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