Research in Engineering Education Symposium &
Australasian Association for Engineering Education Conference
5 – 8 December, 2021 - Perth, WA

Enhancing maths teaching resources: Topic videos and tutorial streaming development

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ABSTRACT

CONTEXT

Engineering maths courses can be challenging for first- and second-year undergraduate engineering students. This situation is especially aggravated when those courses are delivered simultaneously to students representing different degrees, such as Science, Engineering, Information Technology, and Education. In addition, traditional didactic methods, such as lecturer-led teaching, fail to enthuse and inspire students, leading to their disengagement from the course, high failure rate, and eventually lack of student retention.

PURPOSE OR GOAL

This study aims to better relate mathematics courses with engineering applications by encouraging active-learning participation from students. The objective is to develop a set of teaching resources for each of the teaching modules within the course. These resources include topic videos and streamed tutorials, which supplement what is currently offered. This strategy develops extra resources to engage and support students without necessarily changing how the courses are taught.

APPROACH OR METHODOLOGY/METHODS

The Engineering curriculum for the Bachelor of Engineering (Honours) at Griffith University comprises three Mathematics courses. The second-year course, Calculus II, was used as a case study for this pilot project. Topic videos (video bites; 10 to 20 minutes duration) were developed to assist students in developing their understanding of the content and articulate the learning outcomes of each module and their applicability to different engineering contexts. In addition, sets of tutorial problems that target different levels of maths knowledge (starting, intermediate, challenging) were developed to better engage students at different skill levels. These streamed tutorial sets address the varied mathematical ability within the cohort, better supporting both underperforming and advanced students who want to be challenged. The teaching resources were implemented in the teaching period March to June 2021; their effectiveness was measured through surveys and individual/group interviews. Failure rates and grade distributions were assessed by comparison with data obtained from previous cohorts.

ACTUAL OR ANTICIPATED OUTCOMES

The proposed online resources supplemented the current teaching material to better enhance the learning experience of all students, with an emphasis on the Engineering cohort. Outcomes included increased student engagement and reduced failure rates, as the targeted resources better supported students with different maths abilities.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The teaching resources developed in this pilot project may be implemented in all course delivery modes, including online and blended alternatives, making it an attractive additional online resource that can easily be implemented in current pandemic times. The success of the pilot project provides indications of benefits for other schools and programs to apply a similar approach in their maths or other multidisciplinary courses.

KEYWORDS

Mathematics, active learning, educational videos, tutorials, flipped-classroom, teaching resources.

Introduction

Mathematics plays a crucial role in engineering education. Mathematical concepts are indispensable as they describe, analyse, and make sense of the world around us. They allow us to solve problems that arise in all engineering fields (Neale, 2020).

Sound knowledge of mathematics and practical skills to solve maths problems are essential in engineering practice; therefore, students are expected to demonstrate them in maths-related courses/units, especially in their first year of university studies. However, literature and practice show that traditional didactic methods fail to enthuse, inspire, or educate students and may lead to a negative attitude towards the subject and increased cynicism toward its applicability in real life (Wilkins and Ma, 2003). It also has an adverse effect on student outcomes: for example, first-year maths engineering courses at Griffith University have shown failure rates of approximately 34% and 36% in 2017 and 2018, respectively, with a cohort size greater than 140 students. The structure of these courses focuses on fundamental concepts at the expense of discipline-specific content due to the cohort's wide range of needs, which includes Science, Engineering, Information Technology, Computer Science, and Education students.

Adding to this issue, completing prerequisite subjects/courses is no longer a requirement for entering engineering degrees; instead, degree admission criteria typically list ‘assumed knowledge’ recommended for commencing students. For instance, in Australia, Mathematical Methods is a subject available to Year 11 and 12 students interested in pathways such as engineering (Evans et al., 2019). The subject is not a tertiary-level entry requirement; it is currently listed under the admission criteria as ‘assumed knowledge’, which indicates the minimum level of knowledge required to undertake an engineering program. Although universities offer a range of bridging opportunities for those students who have not completed the subject or lack the formal qualifications, assumed knowledge is not assessable, which means that any student can apply and enter an engineering program without such knowledge. This potentially poses a risk that students without the necessary assumed knowledge may have difficulty completing first-year engineering maths courses, leading to disengagement, failure, or withdrawal.

It is, therefore, crucial to develop and implement resources that aim to better enhance the learning experience of all students, increase student skills and engagement, enhance student learning outcomes, improve knowledge retention, and reduce failure rates. A meta-analysis of 225 cases demonstrated a 6% increase in grades and a 33% reduction in student failure when active learning is introduced (Freeman et al., 2014). Vos and de Graaff et al. (2004) showed that an active learning approach increases student performance in science, engineering, and mathematics.

Bhagat et al. (2016) suggested that current technologies, including online quizzes and videos, can benefit students, especially low achievers. These resources enable students to learn at their own pace, access online videos before each class, and then use the class time to participate in the learning activities, such as problem-solving and discussion.

Other resources to enhance mathematics courses that have proved effective include the use of computer algebra software (CAS) (Ooi, 2007); step-by-step problem-solving through worked example videos (WEVs) (Kay and Kletskin, 2012, Dart et al., 2020), and problem-based learning approaches (Masitoh and Fitriyani, 2018). Several studies have shown that educational videos are effective educational tools that enhance learning (Rackaway, 2012).

This paper presents a series of learning and teaching resources intended to supplement existing teaching activities in engineering mathematics courses. These additional resources aim to better engage and support students in their learning process without fundamentally changing how the courses are being taught. These resources include (1) topic videos to enhance the student understanding of the course content and (2) streamed tutorials to suit different math knowledge levels, providing students with a personalised or adaptive approach. Both resources, particularly (2), can easily be adopted in online or blended delivery modes. This is particularly important in current times, where face-to-face teaching has been disrupted due to COVID-19, and educators have been forced to move learning activities to online delivery (Espinosa et al., 2021).

Methods

The Engineering curriculum for the Bachelor of Engineering (Honours) at Griffith University comprises three Mathematics courses: Engineering Mathematics 1 (1010ENG) and Engineering Mathematics 2 (1020ENG) in the first year, and Calculus II (2205NSC) in the second year. Similar to other Engineering programs in Australia, the content covered in the three courses include linear algebra, complex numbers, functions, integration, differentiation, vector calculus, and differential equations.

The second-year undergraduate course, Calculus II (2205NSC), was used as a case study for this pilot project. The course was offered in a flipped-classroom delivery mode in the first teaching period (Trimester 1), March to June 2021. Topic videos (video bites; 10 to 20 minutes duration) were developed to assist students in developing their understanding of the course content and articulate the learning outcomes of each module and their applicability to different engineering contexts. In addition, sets of tutorial problems that target different levels of maths knowledge (starting, intermediate, challenging) were developed to better engage students at different skill levels. These streamed tutorial sets address the varied mathematical ability within the cohort, better supporting both underperforming and advanced students who want to be challenged.

Calculus II is divided into four modules, and it covers aspects of vector calculus in 2D/3D, ordinary differential equations, partial differential equations, and Fourier analysis. These topics serve as a base for further courses in the engineering degree, such as electromagnetic fields, fluid mechanics, structural analysis, and signal processing.

The course is offered once per year over a 12-week period. It consists of 24 hrs of 'lectorials' (1 × 2 hrs/week for 12 weeks) and 22 hrs of tutorial sessions (1 × 2 hrs/week for 11 weeks). Both the lectorials and tutorials can be delivered online or face-to-face. The lectorials are sessions dedicated to Q&A from the video bites and numerical problem-solving practice. The course assessment is composed of an online diagnostic quiz conducted at the beginning of the teaching period (2%), three quizzes (30%), three online practice assessments in preparation for the quizzes (8%), ten tutorial mini-quizzes (10%), and a final exam (50%).

Video bites

Video bites consisted of a series of around 5 or 6 topic videos per week, each approximately 15 mins long. One of the well-known problems with using educational videos is that context can be lost if the material is too brief or presented without context. On the other hand, extended videos result in student disengagement. Fifteen-minute videos provided a good compromise, as they allowed to cover the topic in detail and solve some numerical problems.

According to Brame (2016), to maximise the benefit from educational videos, it is important to consider the following recommendations: (1) *keep the videos brief and targeted on learning goals*, (2) *use audio and visual elements*, (3) *use signalling to highlight important concepts*, (4) *use an enthusiastic delivery style to enhance engagement*, and (5) *embed the videos in a context of active learning*. This can be done, for example, by using interactive elements and guiding questions.

Each video bite began by linking previous bites and establishing the significance and context for the current bite. New learning was then presented, followed by an example with a focus on methodology and decision-making. Students were encouraged to pause the video and attempt a given problem to help reinforce learning. Lecture slides, with space for students to add their notes, were provided to complement the videos, assist meaningful note-taking, and encourage students to work through problems with the presenter.

The video bites were developed with the free and open-source cross-platform OBS Studio (obsproject.com), using a Wacom One Creative Pen Display tablet (Wacom.com). The videos were edited with the software Camtasia (techsmith.com). The video editor allows the videos to be incrementally improved over the years, keeping them up to date in terms of video quality and content.

Before recording each video, a script was developed to reduce recording time and minimise cut sequences. The videos were uploaded to the university's learning management system Blackboard (blackboard.com). In the future, it is intended to upload the videos to an online video sharing platform (i.e., YouTube) so they can be available to the broader education community.

The videos were supported by a 'lectorial' each week. These lectorial sessions allowed students to ask questions about the content and allowed them to discuss applications, giving value to what was learnt. Several examples would also be worked through, focusing on each of the main skills developed that week. Questions considered included discipline-based applications, providing relevance to learning.

Gratchev and Jeng (2018) suggested that students appreciate the course content better if they see how it can be applied to real-life applications. As an example, one problem considered a differential equation that modelled the behaviour of an industrial robot arm used to move salt pellets, determined the type of natural response we could expect, and discussed why that is important for this application. Another example considered solving a differential equation to find the voltage across a capacitor in a resistor-inductor-capacitor (RLC) circuit.

Tutorial streaming

One set of tutorial problems was developed for each of the tutorial sessions, and each tutorial set was divided into three different levels of difficulty: starting, intermediate, and challenging. The tutorial set was made available to the students one week before the tutorial session. Students were encouraged to attempt the problems from all skill levels before attending their session.

In the teaching period of 2021, tutorial sessions were delivered face-to-face. During the two-hour session, students were divided into groups of five and asked to continue working on the problems in a discussion group. The tutor would then walk around the groups and offer personalised assistance; if common questions or struggles arose, the tutor would then solve specific problems step-by-step in front of the class. Once all tutorial problems were discussed and solutions verified, the tutor conducted a mini quiz for about 10 minutes (generally at the end of the session). The mini quiz consisted of three numerical problems with difficulty sitting between 'starting' and 'intermediate' levels.

Each tutorial set consisted of approximately 12 problems (four for each skill level). All questions, primarily designed in an abstract form, provided a progressive understanding of each topic delivered in the video bites. As an example of the skill level structure, after the 10-minute video bite on 'Gauss's Theorem' and the corresponding lectorial session, which was mainly dedicated to Q&A, students would then attempt the following problems before their tutorial session:

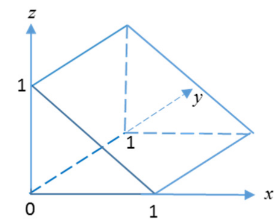
- *Example of a 'Starting level' question*

A 3D vector field given by $\underline{\mathbf{V}} = 3x^2\underline{\mathbf{i}} + 2y^2y + y\,z\mathbf{k}$, represents the flow of water in a system.

Use Gauss's theorem to find the overall flow of water out of a box with $0 \le x \le 1$, $0 \le y \le 1$, and $0 \le z \le 2$. According to whether your answer was positive, negative, or zero, provide an interpretation of the result.

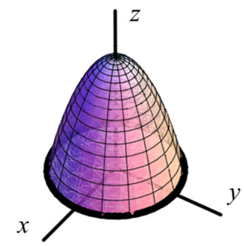
- *Example of an 'Intermediate level' question*

The following figure shows a wedge-shaped closed surface, defined by $x + z = 1$ and the planes $x = 0$, $y = 0$, $y = 1$, and $z = 0$. For the vector field $\underline{\mathbf{V}} = xz\underline{\mathbf{i}} + yz\underline{\mathbf{j}} + z\underline{\mathbf{k}}$, find the overall flux out of the wedge's surface using Gauss's theorem. According to whether your answer was positive, negative, or zero, provide an interpretation of the result.



- *Example of a 'Challenging level' question*

Let V be the solid bounded by the x-y plane ($z = 0$) and the paraboloid $z = 4 - x^2 - y^2$. Let S be the boundary of V (the paraboloid and a disk with radius 2 in the x-y plane), oriented with the outward-pointing normal. Find the overall flux out of the paraboloid and disk using Gauss's theorem where the vector field $\underline{\mathbf{V}}$ is given by $\underline{\mathbf{V}} = (xz\sin(yz) + x^3)\underline{\mathbf{i}} + (\cos(yz))\underline{\mathbf{j}} + (3zy^2 - e^{x^2+y^2})\underline{\mathbf{k}}$ and $0 \le \theta \le 2\pi$ in cylindrical coordinates.



As mentioned previously, tutorial problems were primarily designed in an abstract form due to students from different cohorts (i.e., education, science, and engineering) being enrolled in the course. It is, however, in the project plans to expand the tutorial list to include more discipline-specific problems with varying levels of difficulty. This would be particularly suitable for implementation in courses with little desire or ability to adjust the current delivery.

The tutorial sets allowed the teaching team to ascertain individual and overall student performance. If most students struggled with problems at a particular skill level, more emphasis was then added to those problems; otherwise, the tutor would move faster to the following skill level. From the students' perspective, the different levels of difficulty allowed them to determine their understanding of the course content and encourage them to seek immediate help if they were struggling with the 'starting level'. This was important because both quizzes and the final exam were designed based on the 'intermediate level' of difficulty. On the other hand, if students could reach the challenging problems with no difficulty, it would allow them to move confidently to further topics.

Results

To assess the effectiveness of the teaching resources, assessment results for 2021 were compared to results from the preceding six years. Both resources were fully implemented for the first half of the course, so the first assessment item (quiz 1) was used for the analysis. Figure 1a shows the pass/failure rates from 2015 to 2021. As it can be seen, from 2015 to 2019, the failure rate was ≥ 30%; this decreased to 24% in 2020 and 16% in 2021. It is important to note that since 2020, COVID-19 has had a noticeable impact on the overall student outcomes. Although randomised questions and randomised variables were used in the assessments, there was no formal invigilation.

In 2020, additional tutorial questions were partially introduced. In 2021, streamed tutorials + lecture video bites were introduced through the first half of the course, and video bites in the second half (no streamed tutorials).

Figure 1b shows the student outcomes for one of the assessments (quiz 1 – marked out of 10), for the total number of students (110) enrolled in 2021. As can be seen, more than 35% of the students received a high distinction (≥ 8.5/10). This percentage is greater than previous years where it was approximately 20%-25%.

In addition, student feedback in 2021 was collected through a general qualitative and quantitative survey containing the following questions:

Q1. This course was well-organised.

Q2. The assessment was clear and fair.

Q3. I received helpful feedback on my assessment work.

Q4. The course engaged me in learning.

Q5. The teaching team was effective in helping me to learn.

Q6. Overall I am satisfied with the quality of this course.

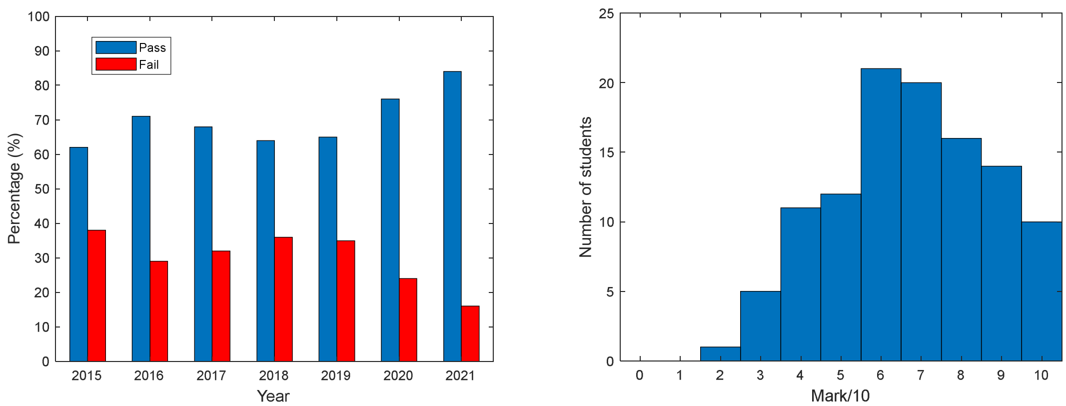


Figure 1: (a) Pass and failure rates from 2015 to 2021 of one of the assessment items, (b) student outcomes for one of the assessment items (marked out of 10) in 2021.

The questions were scored using a 5-point Likert-type response scale, from 1 (strongly disagree) to 5 (strongly agree). The response rate was 30%. Figure 2 summarizes their responses. The 5-point scale was converted to a total score out of 100.

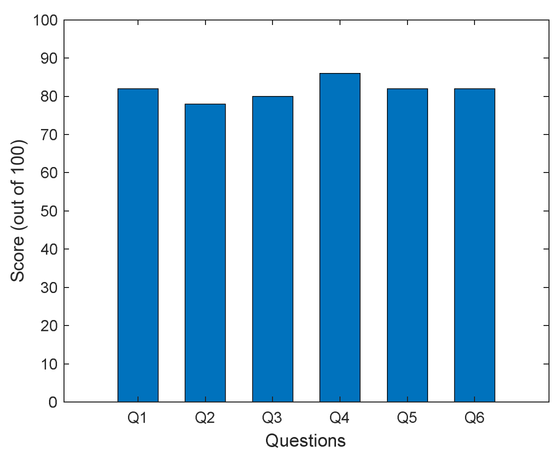


Figure 2: Anonymous survey response from undergraduate students in Calculus II, 2021. Questions 1 to 5 scored out of 100.

According to the feedback, students found the course engaging (average score 86/100) and well organised (average score 83/100), highlighting the importance of the video bites, as they found them valuable and easy to follow. They stated that the videos enhanced their understanding of the course content and their learning in general.

Students found the lectorials helpful, as they helped them connect the conceptual theory with practical engineering applications. In addition, they found the streamed tutorials very well designed, structured, and implemented, as they tested their capabilities through the different levels of difficulty. This allowed better engagement by high performing students, as well as those that were struggling. Their ability to work at their own pace was recognised as an essential factor for their learning.

The following excerpts from student feedback provide some insight into their learning experiences:

"Excellent structure and clarity to lecture bites which made learning and understanding the content significantly easier."

“Video bites were very clear, easy to understand and overall, extremely helpful.”

“I personally loved the way the streamed tutorial problems were designed, as they allowed me to work and understand the basics (with simple problems) then work my way through and move on to moderate and more challenging problems.”

Concluding remarks

As a result of using video bites and streamed tutorials, the maths course targeted by this pilot project was able to better cater to the individual learning styles of its diverse student cohort. The approach used allows either full flipped-class implementation or as supporting resources for a more traditional style. In the flipped-class approach, the lectorials allowed clarification of concepts where students were unclear, and the ability to discuss applications and interpretation of answers, thereby providing a link between the math and the real-world to which it is being applied. By incorporating questions of different competency levels in the streamed tutorials, students of all competencies can participate and achieve some success and be motivated to work their way through to the higher levels of difficulty. Results and feedback showed that students not only enjoyed the course design and resources but improved their learning as well. These results indicate benefits for other universities and programs to apply a similar approach in their maths or other multidisciplinary courses.

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Acknowledgements

The authors would like to thank Griffith University Sciences Group Strategic Learning and Teaching Grants for funding and supporting this project.

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