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A pilot study into developing animations for electrical and electronic engineering curriculum

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ABSTRACT

CONTEXT

Many electrical and electronic engineering (EEE) programs comprise courses that cover a great deal of mathematical and physics-based fundamentals and link them to important engineering concepts. Compared with courses in other engineering disciplines, it is commonly observed that undergraduate EEE students often struggle with grasping the content since by nature they are mathematical, abstract, and intangible. Many respond more effectively to visuals rather than mathematical proofs and equations, but often the EEE instructor is limited to presenting **static** graphs and diagrams. Students are then expected to construct their own mental representations of the concepts, which is often a challenging task.

PURPOSE OR GOAL

The goal of this pilot study was to investigate the effectiveness of using narrated animations to help EEE students in two cores courses (Signals and Systems, Electric Circuits) understand concepts that are mathematical, abstract, and intangible by nature. The hypothesis was that “bringing these concepts to life” would enable students to better understand and comprehend them.

APPROACH OR METHODOLOGY/METHODS

In order to create animations that are both high quality and suited for technical content, the study used the *manim CE* (community edition) Python library, which provided a programmatic way of accurately rendering mathematical and graphical objects. The Signals and Systems course was used in this pilot study. The topics selected were convolution and Fourier series. The videos generated by *manim CE* were narrated together with inspirational background music and shown to second year students enrolled in the 2305ENG Signals and Systems, after they had covered the concepts in traditional lecture form. The students were then asked to complete a survey to gauge the effectiveness of the animations in helping them understand the concepts.

ACTUAL OR ANTICIPATED OUTCOMES

The students found that the animations were helpful to their learning and understanding. They also indicated that the videos clearly showed the transformation from one step to another, which is very important as this shows the value in using the animation to enhance the students learning and understanding.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

Overall, the students seemed to be positive with the structure, design, and targeting of the animations. They also felt that the animations complemented their learning. This was an encouraging result which indicates that the animations will be a benefit for theoretical courses and development of animations should be pursued.

KEYWORDS

visual learning, visual resources

Introduction

The art of Engineering education requires the educator to be able to impart the many abstract Engineering concepts in a fashion that the student will be easily able to comprehend, retain, and use as a foundation for later learning. Since the Engineering curriculum builds upon the student's pre-existing knowledge then it is important for the student to have a good grasp of the material taught previously. Engineering is a blending of both the practical skills and theoretical concepts of which the theoretical concepts can be the most difficult for students to visualise. Hence educators are looking for different methodologies to help with the visualisation of the material. This is confounded by the changing requirements and attitudes of the post-covid student cohort. The material presented must be engaging, flexible and adaptable to address the student's learning needs and circumstances and should not just be text or a series of web pages which can overload the students. It also needs to be presented in a mode that allows the student to address the demands of their work-study balance. Therefore, the Educator is always looking for different teaching aids to help address these needs (Ismail et al., 2017)

The use of multimedia has been well explored in the literature (1,2,3) and has been applied to Engineering and Mathematics with some success (Ellis, 2004; Fu, 2022; Gero et al., 2014; Ismail et al., 2017; Rohendi et al., 2022). Multimedia refers to multiple delivery modes of the information presented to the learner at the same time e.g. images and speech (Mayer, 2009). The delivery modes may take the form of text, speech, and dynamic or static images where animation is a form of presenting the images dynamically to illustrate a concept. (Mayer, 2009). Ellis (2004) reports that animation indicates that a greater degree of learning is apparent when compared to text. Therefore, animation is an important part of the multimedia approach when coupled with text or speech.

The multimedia approach to learning is effective based upon cognitive theory of multimedia learning (Fu, 2022; Mayer, 2009). This theory states that the multiple information channels used in the multimedia allows the learner to integrate them to form a visual representation which is then linked to pre-existing knowledge in the long-term memory. This is based upon three principles from cognitive science (Mayer, 2009): the Dual channel principle – separate channels for narrative (text/speech) and pictorial information; the Limited capacity principle – only a few items can be processed by each channel; the active processing principle – the learner needs to engage in the process of cognitive learning for meaningful learning. Mayer (2009) also states that "effective multimedia instruction requires not only presenting the relevant material but also guiding the learner's cognitive processing of the material."

There are many packages available for educators to create multimedia presentations and animations. However, these tend to have a steep learning curve which requires the educator to purchase, use, and learn a specialist animation/multimedia packages. Since lots of packages contain features that are not required or suitable for the Engineering topics which typically requires the display of calculated parameters, signals, graphs, with many of these involving repetition, then this leads to steeper learning curves. If the learning curve is too high, then the tool will likely not be used. What is needed is a simple, familiar, mathematically based, and preferably open-source method to generate animations without the requirement to purchase and learn many specialist animation/multimedia packages suitable for the Engineering topics especially in the display of calculated parameters and signal pathways, and repetition. Software packages, such as the *manim* project (manim community, 2023) enable the development of animation videos in mathematics, graphics, and geometry using Python code, which allows for very flexible and precise control of all elements. The advantage of using the Python programming language is that it is a widely used, well accepted, and easy to learn programming language.

This paper presents a pilot study using two fundamental engineering courses with the aim to investigate the use of Python software to create high-quality and professional animation videos that encourage and enhance visual-based learning of otherwise abstract and non-tangible concepts in engineering courses. This study was supported through an internal teaching and learning grant.

Background

The manim CE library and installation

There are currently two main versions of the manim (Mathematical Animation Engine) python library that are currently being developed. Manim (manim, 2023) was developed by Grant Sanderson to generate and render videos that explained various mathematical concepts on his 3Blue1Brown Youtube channel. This version is still being developed and adapted by the author. The second version is the manim CE or community edition (manim community, 2023), which is a forked version of the original Manim with the goal of providing a more stable and user-friendly library with better tutorials, documentation, and community support. This project used the community edition of manim.

Being a python package, the pip (Pip Installs Packages) package manager is used to install the manim package (pip3 install manim) on platforms such as Windows, Linux and MacOS. It is recommended to install manim in a virtual Python environment such as venv or virtualenv. The coding can be performed using a text editor or in popular IDEs such as Visual Studio code, which can run an extension called Manim Sideview, which provides the user with a more integrated and user-friendly development environment.

Manim CE programming concepts

Video animations are created by writing a Python program that contains a *scene*. These scenes are constructed by creating a Python class that inherits the Scene class in manim CE. Within the class, a construct method is used to specify all aspects of the animation, from the creation of mathematical objects (also known as a Mobject) to animation rendering and timing. The sequence of events is coded procedurally by firstly creating the mobject and specifying its parameters such as colour, length, text, etc. Mobjects can be positioned using absolute co-ordinates or in terms of co-ordinates that are relative to other mobjects.

The animation of mobjects can be specified in several ways, such as transforming from one mobject to another or built-in transformations such as scaling and rotation. These animations are rendered via the play method. The timing of events is typically controlled by inserting a call to the wait method, which accepts the number of seconds as a parameter. Mathematical text and equations are constructed and rendered in the video as LaTeX equations and these can be animated via translations, rotations, colouration, and transformations, providing useful and important visual cues to the audience.

The video is rendered into an mp4 file by the manim CE tool with options available to control the size and quality of the rendered video. This can be useful during iterative development where minimal render time is preferred.

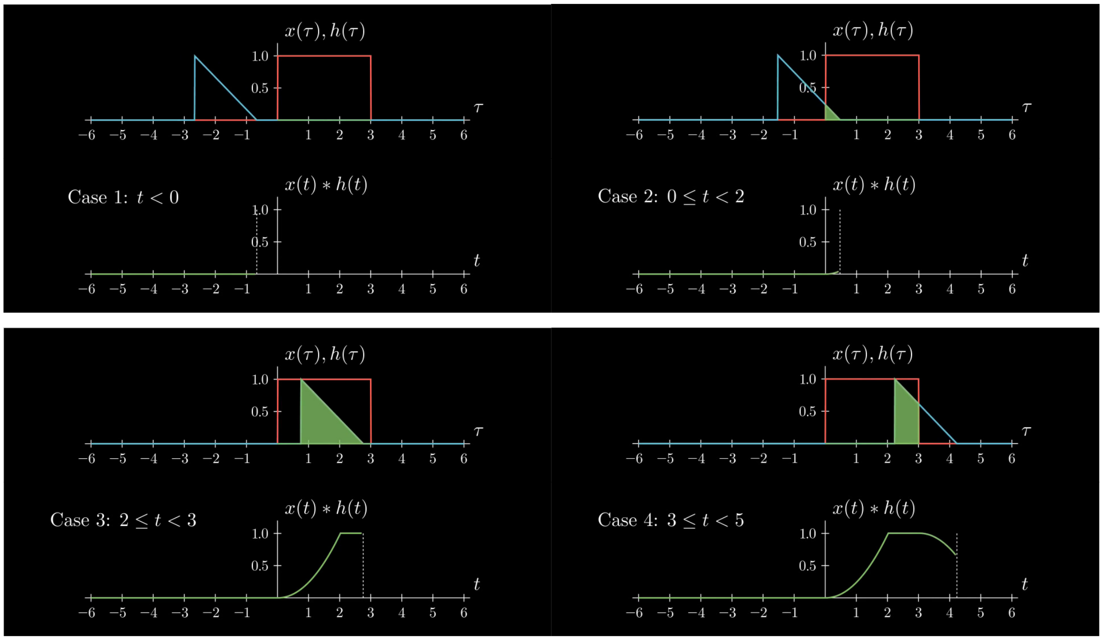

Figure 1: Screenshots showing the different cases of *t* when computing convolution

Methodology

This pilot study developed animations for a diverse range of courses, including electric circuits (1301ENG), and signal and systems (2305ENG). These target courses were chosen to facilitate the development of the required utilities and templates to suit courses in Electrical and Electronic Engineering which could benefit from animations as part of their resources with an aim to provide a starting point for a wider suite of tools which could be used for courses in other disciplines and schools. Feedback from the student surveys was used to gauge the effectiveness of the animations and to guide future work.

The methodology was divided into 3 main parts.

1) Development of the trial animations in Manim;
2) Present animations to students in the signals course; and
3) Survey students to determine the effectiveness of the animations to their learning and to gain an understanding of what worked / did not work.

1) Animation video development in Manim

To explore the benefits and possibilities of the manim CE package, a pilot study was conducted to create animation videos for the Signals and Systems and Electric Circuits courses. The Signals and Systems course was selected as a first trial because of the high degree of mathematical concepts involved, which was deemed to be a good fit for the capabilities of the manim CE library. The study then considered the use of manim CE for the Electric Circuits course, which was more involved due to the need to draw circuit elements.

2) Develop and present animation videos

Development of Signals and Systems animation videos

Suitable topics were selected from the Signals and Systems curriculum during meetings between the course convenor (who was part of the project team) and a student developer. The selection criteria that were used related to the amenability of the concept to be drawn and animated as well as the observed difficulties in effectively conveying the concept in past deliveries of the course within a traditional lecture setting. Two topics were eventually selected, namely convolution and the Fourier series representation of signals.

The sequence of events in each animation video was planned and designed by using a storyboard (Birchman et al., 2006), which is a popular tool for capturing the sequence of visual elements so that they can be weaved together to form the story. This was important for the development of the video for convolution, which can be broken down into a series of steps: (1) time reverse one signal; (2) identify the different cases; (3) shift the time-reversed signal by *t* for the first case; (3) multiply with the other signal and integrate; and (4) repeat step 3 for subsequent cases. Each of these steps can be easily animated in manim CE, providing important visual-based understanding of an otherwise abstract mathematical operation, as seen in Figure 1 above. Visual cues in the form of different colours were used to highlight parts of interest, as seen in Figures 2.

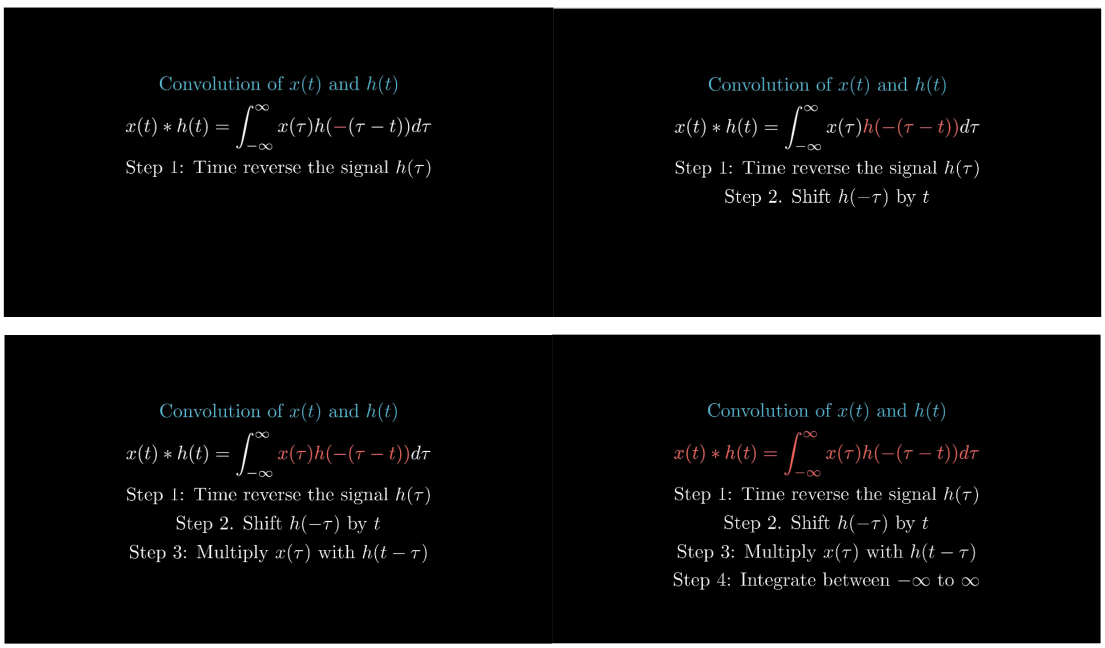

Figure 2: Screenshots showing the use of colour to highlight individual terms for each step of convolution

In the Fourier series video, a large degree of animations was used to demonstrate the superposition of harmonically related sinusoids to construct a square wave. As shown in Figure 3, the individual sinusoids were constructed on the bottom graph to show that they were harmonically related, and each one of these were moved to the other graph to be added to the Fourier series approximation. The challenge was to develop scenes that were informative but not too informationally dense or cluttered.

Each video was accompanied by narration as well as inspirational background music. These were added into the manim video using basic video editing tools.

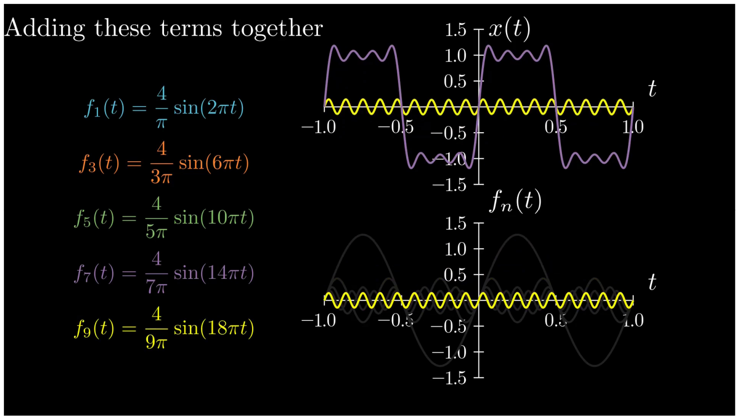

Figure 3: Screenshot of Fourier series video using animations and colour to show the construction of a square wave using harmonically related sinusoids

Development of Electric Circuits video resources

Suitable topics were selected from the Electric Circuits curriculum during meetings between the course convener and student developer. Figure 4 shows a screenshot of an early development version of the mesh current analysis video. The closed loops of the circuit were first highlighted and then each loop was zoomed in, where the mesh current equations were derived.

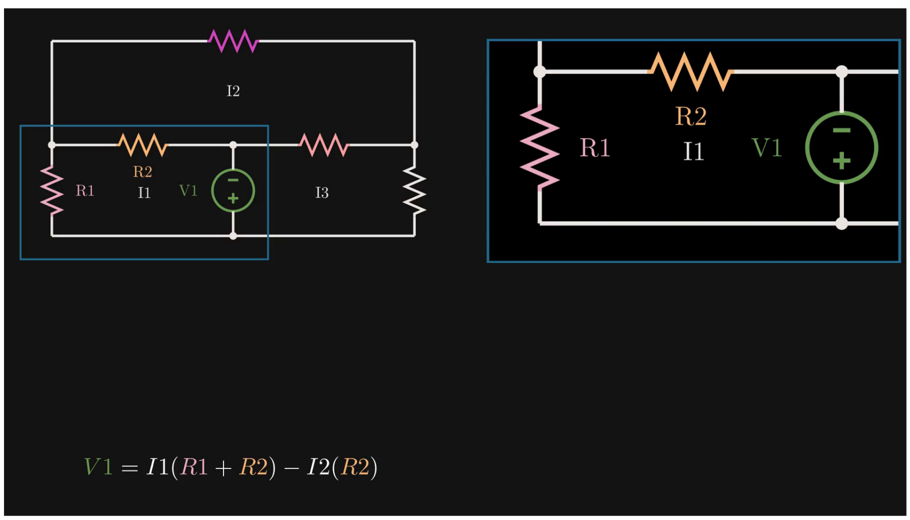

Figure 4: Screenshot of video showing mesh current analysis of a circuit.

3) Student survey evaluation

To evaluate the effectiveness of the developed manim videos, students enrolled in Signals and Systems were asked to watch the convolution and Fourier series videos during a laboratory class and then complete an anonymous paper-based survey (HREC: 2023/192). The survey was conducted several weeks after the content was presented in class. Within a practical in-person teaching session, students were asked to review the animation and complete the paper-based survey. The survey comprised six questions (Table 1) where students responded on a five-point Likert-scale (strongly agree, agree, neutral, disagree, strongly disagree). The statements can be arranged into three categories:

1. The animation assistance in aiding the student's understanding (S1, S4, S6)
2. The relationship of the animations to the course in which it was delivered (S3)
3. The mechanics of the animations to help guide future design (S2, S5)

Four open-ended questions (Table 2) were also included in the survey.

Table 1: Likert-scale questions on student survey

#	Question
S1	The animation videos were easy to understand through visualisation
S2	The duration of the animation videos was appropriate
S3	The animation videos complement the lecture content of the course
S4	The narration in the animation videos was informative
S5	The speed of the narration in the animation videos was appropriate
S6	I understood the concepts better via the animation videos than via the lectures

Table 2: Short-response questions on student survey

#	Question
Q1	What other topics would you suggest that the other students would find beneficial from this type of animation video?
Q2	What did you like the most from these animation videos?
Q3	What did you like the least from these animation videos?
Q4	Do you have any suggestions for improving the animation videos?

Analysis and Discussion

The results section is broken into two separate sections. The first section gives the results from the student survey to gain an insight into the effectiveness from the student's perspective.

As can be seen from Figure 5, the responses ranged from Neutral to Strongly Agree. This indicates that the students did not have any strong negative impression to the animations. The range of responses to this pilot study will be very useful in guiding the future direction and design of the animations.

The students found that the animations were helpful to their learning and understanding as shown by the high scores in the distributions in statement 1 and statement 4. This was also supported by some of the open comments about the animations in which over half of the students' made comments such as “they were clear and to the point”, “How clearly you can see the transformation from one step to the next.”, and “Very easy to follow and understand.” The comment that the videos clearly showed the transformation from one step to another is very important as this shows the value in using the animation to enhance the students learning and understanding. This was one of the motivations for this pilot study to use an alternative method of producing the animations. The large number of Neutral responses in Statement 6 may have been due to the survey running after the lecture material for the Convolution and Fourier topics were covered. It was likely that most of the students would have already understood the material and mastered the content so it would have been harder for them to judge hence a neutral response.

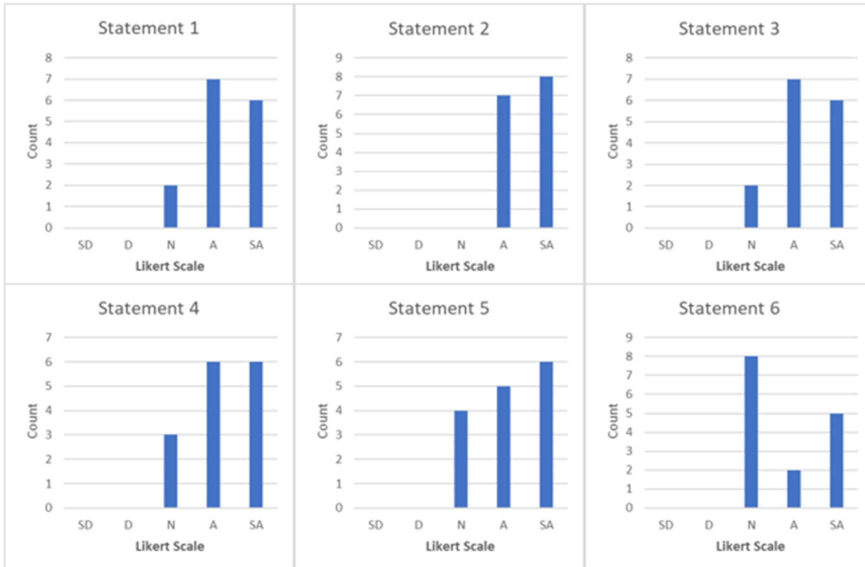

Figure 5: The student responses (n=15) to the survey of six statements given in Table 1.

Most of the students were in agreement with statement 3 that the videos complemented the lecture material whereas half of the students indicated that it helped them understand the concepts better. This is supported by comments such as "it gives me a deep understanding of convolution and fourier transform". The students also indicated that the animation method would be suited to other courses which employ mathematical concepts since when asked in the open questions which other topics would they suggest other students would find beneficial from this type of animation video, all the respondents indicated mathematical topics such as calculus, transforms, and orthogonal representation of signals.

Statements 2 and 4 involved the mechanics of the animations, in particular, the design and structure of the animations via speed of narration and duration of the animation. The scores indicated that the students were quite happy with the structure and design of the videos. This is supported by the fact that there were no comments about the speed or duration in the open questions. Also, most of the students were not able to think of a way to improve the animations. However, there were some open comments in which the students wanted the actual animation to be slightly different such as reducing the number of overlays, and the animation to be applied to different and more complex examples.

Conclusions

This paper was a pilot study into the use of manim to generate animations for students in two fundamental courses which involve theoretical understanding. The animations were successfully generated programmatically using the Python programming language.

Overall the students seemed to be positive with the structure, design, and targeting of the animations. They also felt that the animations complemented their learning. This was an encouraging result which indicates that the animations will be a benefit for theoretical courses and development of animations should be pursued.

Future work will involve fine-tuning animation designs based upon the survey comments and applying the animation technique to other theory-based courses. Also, there was a significant development phase by the coder which can be improved now given that we have gained experience and understood the limitations of manim. We are also aiming in the future to simplify the animating process for less programming-oriented users, perhaps aiming towards creating libraries and examining ways to do low-code coding.

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