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Online Delivery of Solutions-Based-Learning Focused Tools for Engineers with Global Impact

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ABSTRACT

CONTEXT

A major defining aspect of engineering involves solving problems, and over recent years there has been significant development of problem-based-learning approaches to engineering education. While this puts the focus on the problem, which can be highly motivational for students, it is perhaps equally important to highlight the solutions, in what might be called a Solutions-Based-Learning approach to engineering education.

PURPOSE OR GOAL

This paper presents a Solutions-Based-Learning (SBL) approach to teaching, in which topic material is packaged and presented through a lens that focuses on its relationship to its use as an 'engineering tool'. Tools empower engineers to solve problems and design the future, effectively, efficiently, and practically. When students understand that they are continually building their toolkit, it can be highly motivating and truly empowering. If this tool-focused approach can be delivered online it is even more powerful and can have global impact for engineering education.

APPROACH OR METHODOLOGY/METHODS

Viewing course content through a "tools" lens, has led to focusing on the 'what', 'how' and 'why' questions that students naturally have as a starting point when confronted with new engineering challenges and topics. More specifically, 'What is this new tool?', 'How does it relate to my existing toolkit?', and 'Why is it useful to me?'.

A major component has been the production of 190 short videos to support student-centred learning at a self-directed flexible pace, and in three main learning modes: 1. As components of a whole Unit (subject), structured around focused tools/topics, interleaved with practical problem solving sessions allowing students to engage in self-directed problem-solving; 2. As on-demand isolated, searchable, answers to commonly asked questions; 3. As browse-able "fundamental understanding" content, providing a narrative around the tools and the problems they solve.

ACTUAL OR ANTICIPATED OUTCOMES

Student feedback scores in EE UG Unit(s) have been strong, averaging 4.5/5 for questions related to online content. Student grades have improved significantly over the past three years. In one Unit the percentage of D or HD increased from 11.1% in 2019, to 21.2% in 2020, and 34% in 2021. The videos are delivered on a YouTube channel that receives 4000 views daily globally and is ranked in the top 10% of all "education" category YouTube channels globally across all topic areas.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The use of focused and carefully planned videos has proved to be highly effective in reframing engineering education and empowering students with an expanding toolkit of skills for their future.

KEYWORDS

Online Delivery, SBL, Problem Solving, Student Focused Learning, Self-Directed Learning.

Introduction

A major defining aspect of engineering involves solving problems. Over recent years there has been significant development of problem-based-learning (PBL) approaches to engineering education, where the focus is on presenting students with problems that need to be solved, as opposed to traditional didactic lecture-based presentation of material. PBL has been shown to enhance intrinsic student motivation (Norman & Schmidt, 1992) and is a way of encouraging them to think creatively. De Graaff and Kolmos (2003) highlight some of the benefits of problem analysis and project-organised learning, and Sheppard et al. (2011) report that the PBL curricular model is capable of developing desired attributes in new engineers and is proven to develop expertise in students.

However, PBL is not without its shortcomings. While it puts the focus on the ‘problem’, which can be highly motivational for students, it is equally important to highlight the ‘solutions’, in what might be called a Solutions-Based-Learning (SBL) approach to engineering education. An engineering student approaching a new problem without having a toolkit of potential solution techniques from which to draw, is in many ways analogous to an electrician turning up for work without a multimeter or a pair of wire cutters. Problems are motivational, there is no doubt. For example, Yadav et al. (2011) found that “students reported that the PBL approach was more engaging and interesting as it allowed them to construct their own knowledge instead of absorbing teachers’ words and they were able to seek information on their own to solve problems.” And while this may be true, it is vital to consider whether those students were actually *effective* in finding and absorbing the information they were seeking, and whether their own solutions that they came up with were even close to being optimal. Jayasuriya et al. (2007) also discuss the possibilities of learning from peers, but similarly avoid referencing or quantifying this against the possibilities of learning from existing approaches and solution techniques, or drawing on the expertise of experienced engineers.

Problems that students can reasonably do themselves are great for motivation, but they necessarily lack the complexity of industrial problems in the real world, and the solutions they develop themselves for those problems inevitably lack the sophistication of advanced solution techniques, and have limited effect in highlighting broader applications and fundamental insights.

Mills and Treagust (2003) discuss the advantages of both Problem-based and Project-based with examples in Australian universities, as well as Aalborg University. They found that “students who participate in project-based learning are generally motivated by it and demonstrate better teamwork and communication skills. They have a better understanding of the application of their knowledge in practice and the complexities of other issues involved in professional practice. However, they may have a less rigorous understanding of engineering fundamentals.” And surely it is this final comment that points to the prospect that PBL, on its own, is not the panacea some make it out to be. While it is undeniably important for students to be able to work effectively in teams, and have practical application knowledge, surely the most critical element in an engineers’ skillset is an understanding of engineering fundamentals, and an ability to apply those engineering fundamentals to develop *solutions* to problems. If the PBL approach has been shown to result in students having a “less rigorous understanding of engineering fundamentals” then there must surely be something missing.

A Solutions Focus – Fostering Curiosity

This paper introduces a new Solutions-Based-Learning (SBL) approach to engineering education. This approach provides the scaffolding within which PBL can be delivered in a way that supports student learning and facilitates effective solution generation. It is by providing students with a toolkit of engineering solution approaches, developed over decades, that they can approach PBL with confidence. A defining characteristic of an engineer is that they provide solutions to problems, and as the problems of society and industry become ever more complex, it is vital that students learn to build new solutions by drawing on what has been successful in the past, not simply to start from scratch with a problem and ‘seek their own solution’.

Not only does the SBL approach give students the confidence to tackle problems, but it also mirrors what is perhaps the most common experience they will have when they graduate and join the workforce. This is absolutely critical from an employability perspective. Typically, graduate engineers are supervised by an experienced engineer who guides them, works with them, and suggests solution strategies as new problems arise, which they can implement and build upon. Of course they are encouraged to develop their own solution approaches too, within a supported framework, and with the focus squarely on 'the solution'. In the educational context, by taking a SBL approach in partnership with PBL, the focus can be on the solutions, as much as it is on the problems, or perhaps even more so.

A vital component of the SBL approach to engineering education is to identify solution approaches, and present material from a student perspective. By stimulating a student's curiosity about how problems have been solved in the past, it motivates interest, and deepens their learning outcomes. It can form a basis on which to imagine new solution approaches, and consideration of how previously successful solution approaches could be applied to solve completely new problems. This is a fundamentally different approach, compared to the traditional lecture-based presentation of a series of topics in a subject or unit.

Harlim & Belski (2010) explore the benefits of explicitly learning the skills of problem solving, and focusing on solution approaches. Importantly the focus is placed on the solution rather than on the problem. Education of engineers should be focused on developing the engineers' ability to solve problems (Beder, 1999; Roth, 2007). Mayer (1998) posits that problem solving requires domain specific knowledge, the skills to use that knowledge and motivation. Brodie & Brodie (2009) recognise the need to teach students skills to interpret, use and renew information. These are all important components of a SBL approach to engineering education, supporting student confidence to tackle problems and stimulating their curiosity.

A Tools-Based Approach – Building a Toolkit

A critical element of the new SBL approach has been the way in which technical topic material is packaged and presented through a lens that focuses on its relationship to its use as an 'engineering tool' for solving problems. Tools empower engineers to solve problems and design the future, effectively, efficiently, and practically. When students understand that they are continually building their toolkit, it can be highly motivating and truly empowering.

Over the past three years, I have restructured traditional subjects/units at Macquarie University into a dual SBL-PBL mode, totally removing lectures, and in each case identifying 'solutions techniques and tools' in place of more generic and traditional 'topics'. Students have been actively encouraged to think in terms of their personal development of a 'toolkit of solution approaches'. Each new tool enhances their ability to solve the problems that they are confronted with in the PBL component of the respective subject/unit.

I have applied this approach in subjects/units covering topics of Signals and Systems, Probability and Random Processes, Digital Signal Processing, Digital Communications, Information Theory, and Image Processing. In each case students reported improved confidence levels in tackling projects, greater engagement, and improved assessment outcomes.

This solutions-focused toolkit development approach is in no way limited to the specific subjects/units in which it has been employed so far. There is great potential for all engineering disciplines to be reimagined through the 'tools and toolkit' SBL lens. Clearly this is a major shift away from the traditional bottom-up approach of presenting topics starting with a derivation from physical principles. And it is equally not a case of a top-down approach of starting at the system level and delving down into details. The SBL approach goes straight to the heart of the matter for engineers, by focusing first on presenting engineering concepts through the lens of tools that solve problems and using those tools to solve PBL challenges. And then, having established the basics of the tool, proceeding to extend understanding and reinforce the knowledge by delving into the underlying fundamental concepts and derivations that sit behind those tools.

To give a concrete example, consider the Fourier transform (FT) which underpins all frequency domain analysis of any signal or system across all engineering disciplines. In the traditional teaching approach the FT is presented to students as a ‘topic that they need to learn’, following one of the many standard textbooks, by first deriving an equation for a Fourier series (FS) that relates to signals that are periodic, and then presenting a number of results related to the FS, before then moving on to discuss the more general case of non-periodic signals, which leads to the FT. And student feedback tells us that in a majority of cases, after what might typically have been two weeks of material, students still have almost no idea what the FT is used for. On the other hand, in the PBL approach, students typically learn of the FT once they realise a particular problem requires a frequency analysis, and then they proceed to work their way through the textbook, presumably with a higher level of motivation, but following the same standard topic presentation nonetheless.

In the new SBL approach, the FT is first presented in the form of a ‘tool’. The starting point is to understand what it is in general terms, how it differs from other tools the student already has in their personal toolkit, and why it is useful for solving particular types of problems. The next step is to guide students in the use of the FT as a practical tool for solving ‘first order’ engineering problems. And then subsequently to expose students to the fundamental basis that underpins the FT and challenge them to use the tool to solve ‘higher level’ PBL problems.

This scaffolded approach to PBL, by employing the new SBL mode of topic delivery, in a joint SBL-PBL approach, can be employed for any engineering topic or discipline.

Learning Modes – What? How? Why?

Viewing course content through a ‘tools’ lens and a student perspective, has led to focusing on three categories of curiosity-driven learning modes, encapsulated by the questions ‘what?’, ‘how?’ and ‘why?’. These are questions that students naturally have as a starting point when confronted with new engineering challenges and topics. More specifically, ‘What is this new tool?’, ‘How does it relate to my existing toolkit?’, and ‘Why is this tool useful to me?’.

By restructuring course material within the framework of these three questions, it has fundamentally changed the student experience in each of the subjects/units in which I have done it so far. This is a fundamental move away from teaching a topic ‘from the ground up’, topic by topic. It is much more closely aligned with answering the types of questions that students typically type into internet search engines when they are looking to learn about something new to them. By viewing the educational experience from the student’s perspective it seems natural to start introducing new material by first answering the questions that students typically have, and then once they understand what the new tool is going to do for them, their curiosity is sparked to delve deeper, and the more fundamental aspects can follow.

To support this student-centred SBL approach, I have delivered material in units in three main learning modes:

1. The introduction of ‘tools’ as components of a whole unit/subject, structured around focused tools/topics, presented in the ‘what?’, ‘how?’ and ‘why?’ format. This is interleaved with practical problem-solving sessions allowing students to engage in self-directed problem-solving;
2. The provision of on-demand isolated, searchable, answers to commonly asked questions relating to the tools, and more broadly about the overall topics;
3. The provision of browse-able ‘fundamental understanding’ content, providing a narrative around the tools and the problems they solve.

A vital element of these delivery modes has been the development and production of 190 videos that serve both as primary content delivery as well as supporting supplementary material.

Online Video Delivery for Global Impact

The new tool-focused SBL approach has been delivered in subjects/units at Macquarie University in a mixed-mode of in-class practical sessions supported by online content. The online component provides a flexible, on-demand, re-watchable resource to support student learning. By delivering the online content in the form of videos published on a YouTube channel it has proved to serve as an extremely powerful resource with global impact for engineering education.

Video production is itself a valuable tool in an educator's toolkit. Online pre-lecture lesson modules are increasingly popular for teaching STEM related courses (Docktor & Mestre, 2014; Chen, Stelzer & Gladding, 2010), and follow-up videos have also been used by Kong et al. (2017) who created videos informed by post-lecture surveys that targeted specific areas that students had indicated difficulty with. It is extremely important to note that in order to be effective, the production of on-line videos requires vastly more thought, preparation and effort, than simply recording and uploading a lecture/tutorial. Guo et al. (2014) have shown that students often disregard large segments of educational videos, while MacHardy and Pardos (2015) demonstrate that some videos contribute little to student performance. Brame (2016) gives some basic guidelines for making effective videos. A range of factors such as video quality, video length, and the presentation style are known to influence student engagement with videos (Dart, Cunningham-Nelson, et al., 2020; Guo et al., 2014; Kay, 2014), and Mayer (2021) developed a series of principles for designing effective educational multimedia content, advising educators to avoid extraneous material while presenting words as narration rather than printed text. These collective guidelines are very important, however what is perhaps even more important are techniques to address the more subtle aspects of human interaction.

I have produced 190 videos to support my new student-centred SBL at a self-directed flexible pace. My video production technique has focused on providing a personal human-touch, to create the closest possible likeness to an actual one-on-one tutor-student in-person engagement. This is in contrast to basic lecture-style videos or overly produced 'entertaining' educational videos. In the videos that have I have produced, the two most important guiding principles are 'focused content' and 'personal touch/feel'. This includes using hand-drawn diagrams and actually seeing the hands of the teacher pointing at the page while explaining concepts. Computer graphics and text are used only where they genuinely assist with conveying specific points. Also, the written/drawn content for each video is contained to half an A4 page. This achieves two aims. The first is to ensure that the viewer can always see everything that has been presented in the video and does not need to remember material from previous 'slides', and the second benefit is that it serves to limit the topic of the video and ensure the focus is maintained on the specific point (eg. engineering tool) of that particular video.

The key factor in selecting the topic of each video is that it be either on a very specific 'engineering tool', or on a particular aspect of a tool, or on the relationship of that tool to other tools. The primary driving factor in defining the title of a video is that it answers a specific question that a student typically asks when learning about the respective tool. Examples include "What is Beamforming?", "How are Data Rate and Bandwidth Related?", and "Why are Poles Negative in Laplace Transform of Real Stable LTI Systems?" By presenting material in a form that aligns directly and exactly with the student perspective the greatest educational impact is achieved.

In general each video is between 6-12 minutes long, however this timeframe has not been artificially imposed, and when a specific engineering tool has required a longer description, that requirement has guided the length of the video.

The 190 videos have been made available on-line on a YouTube channel that is globally visible and searchable at https://www.youtube.com/channel/UCrltzuSvRbL3rpsvLDnFkuQ . The platform has enabled highly effective delivery across all access modes (desktop, laptop, tablet, phone) and includes automatic subtitles in many languages to assist students of non-English speaking background. The format of the videos has proved extremely popular with students globally (see below for viewing numbers/statistics). The channel receives many comments from viewers across the world every day, expressing their deep gratitude and also requesting new videos be made on related topics (see the YouTube channel where the comments are publicly available under each video).

Playlists have been created on the channel, providing an opportunity to watch a sequence of related videos for those students who seek a more comprehensive view of a particular engineering tool, compared to the focused treatment of each individual video.

In addition to the YouTube channel, a website has been set up that provides a categorized listing of all the videos on the channel, at https://iaincollings.com . The site also includes downloadable PDF summary sheets related to each video, as well as Matlab code for certain videos that students can run themselves.

Results

Topic Areas Developed

To date, 190 videos have been developed covering the following general topic areas:

- Signals and Systems
- Probability and Random Processes
- Digital Signal Processing
- Digital Communications
- Information Theory
- Image Processing

Viewer Numbers and Engagement Metrics

Student feedback scores in EE UG unit(s) where the new SBL approach has been taken have been strong, averaging 4.5/5 for questions related to online content.

Student grades have improved significantly over the past three years. In one unit/subject the percentage of D or HD increased from 11.1% in 2019, to 21.2% in 2020, and 34% in 2021.

The YouTube channel on which the videos are delivered is ranked (according to socialblade.com):

- in the top 9% of all ‘education’ category YouTube channels globally across all topic areas
- in the top 6% of all Australian YouTube channels across all categories

The channel has the following global viewing statistics (according to YouTube):

- 25 Thousand subscribers
- 1.81 Million video views
- 109.8 Thousand viewing hours
- Currently receives 4000 views daily globally
- "Likes (vs. dislikes)" is 98.6%

Also, 8.2% of the videos are watched with automatically generated subtitles, which assists international students and others from demographic subgroups to participate and achieve success in their courses.

From a global perspective, the videos have been viewed in 134 countries. Table 1 shows viewership over the past 12 months listing the top 15 countries.

Table 1: Top 15 Countries by Viewership (past 12 months)

Geography	Views	Percentage
Total	**1092754**	**100.0 %**
India	199338	18.2 %
USA	183388	16.8 %
Germany	54441	5.0 %
United Kingdom	45422	4.2 %
Canada	32290	3.0 %
Turkey	30486	2.8 %
South Korea	22511	2.1 %
Australia	20787	1.9 %
Taiwan	19398	1.8 %
Pakistan	19348	1.8 %
Israel	16600	1.5 %
France	13552	1.2 %
Egypt	13259	1.2 %
Italy	12281	1.1 %
Netherlands	12235	1.1 %

Another important aspect is that the impact of this work goes beyond the main target audience of university undergraduate engineering students. There are many comments left on the channel from people who identify themselves as working in industry (often for many years), PhD and Masters research students, and people working/researching in fields outside engineering, such as quantum physics and economics. By producing targeted focused videos people are able to search and find what they are looking for across a spectrum of fields. Table 2 shows the age breakdown of people who have viewed the channel. The bulk of viewers are in the traditional university age bracket, but there are viewers up to and including the 65+ age bracket who viewed the channel almost 10,000 times in the past 12 months.

Table 2: Age Demographics by Viewership (past 12 months)

Age Bracket	Percentage of Viewers
13−17 years	0%
18−24 years	43.2%
25−34 years	35.4%
35−44 years	12.9%
45−54 years	5.5%
55−64 years	2.2%
65+ years	0.9%

Conclusions

This paper has discussed a new Solutions-Based-Learning approach to engineering education focusing on presenting material in terms of key ‘engineering tools’ that can be used to solve engineering problems. When delivered together with problem based learning in a joint SBL-PBL approach, students have the tools they need to approach engineering problems with confidence and provides greater insights into the fundamentals of engineering.

The use of focused and carefully planned videos has proved to be highly effective in reframing engineering education and empowering students with an expanding toolkit of skills for their future. The viewer statistics for the videos are testament to the engaging, supportive, and inspirational nature of the material, as well as the true global impact they have achieved.

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