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Implementation of the flipped classroom model in a large-scale first-year engineering subject

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ABSTRACT

CONTEXT

The flipped classroom approach reverses the traditional sequence of teaching: students are equipped with conceptual knowledge through pre-lecture content, and this is then consolidated in class through interactive instructor-facilitated activities. This approach lends itself well to the teaching of engineering concepts, given the discipline's heavy focus on applied problem solving. While flipped teaching has been shown to increase student engagement, improve knowledge development, and personalise the learning process, it can be challenging to implement, particularly in first-year student cohorts that are typically characterised by low learner maturity.

PURPOSE

This paper presents the implementation of the flipped classroom model in a large-scale first-year engineering subject. The subject is transdisciplinary in nature, consisting of four modules covering engineering-related professional skills, fluid mechanics, water disinfection, and image processing. The main aim of this implementation was to improve student engagement and enhance their overall understanding of the subject content. This would be achieved through repurposing scheduled lecture time for more hands-on collaborative problem-solving and live coding activities.

APPROACH

As they were taught by the same instructor, the Water Disinfection and Image Processing modules were targeted to investigate the effectiveness of the implementation: the former delivered traditionally, and the latter delivered using a flipped approach. As part of this implementation, ten pre-lecture videos were produced, along with constructively aligned practice quizzes and in-class activities. An anonymous survey was conducted at the end of the semester to gather quantitative and qualitative student feedback on the implementation.

OUTCOMES

Quantitative analysis of the data indicated that the flipped classroom approach generally benefitted student learning and that regardless of prior experience with the approach, students ended up preferring flipped teaching if they had properly engaged with the material. Thematic analysis of free-form student comments identified interactivity, video quality, scaffolding, consolidation, and personalised learning as key advantages of the flipped classroom model. The data also suggested that future implementations should focus on encouraging student uptake of the pre-lecture content via improved signposting and student literacy around alternative instructional approaches.

CONCLUSIONS

The implementation of the flipped classroom model has generally proven beneficial to student learning in this large-scale first-year engineering subject. Encouraging further engagement with the pre-lecture content in future runs of the subject (through imposed assessment or otherwise) might help convince students who remain resistant to giving the approach a fair opportunity.

KEYWORDS

Flipped classroom, first-year engineering, pre-lecture content

Introduction

The flipped classroom model is an instructional approach that reverses the traditional sequence of teaching. Traditionally, in-class time is used to transmit conceptual knowledge from instructors to students, typically through lectures. Students are then assigned homework outside of class to consolidate this knowledge. In the flipped classroom model, this sequence is reversed, with conceptual knowledge delivered through pre-recorded videos or similar resources, which students are expected to review before their class. This allows for in-class time to be better spent on more interactive and collaborative activities, instead of having students passively listen to lectures. These might include instructor-facilitated discussions, hands-on problem-solving exercises, and other activities that encourage active learning (Tucker, 2012; Bishop & Verleger, 2013; O'Flaherty & Phillips, 2015; Karabulut-Ilgu et al., 2018). An extensive body of literature exists around the benefits of the flipped classroom model, which can be encapsulated into the following three themes (O'Flaherty & Phillips, 2015; Akçayir & Akçayir, 2018):

1. **Increased student engagement.** In-class time is freed up for more interactive, hands-on learning experiences. This also allows for more direct and meaningful teacher-student interactions, where students' specific questions/challenges can be better addressed. This overall shift in learning from being primarily one-way and passive to two-way and active boosts student engagement.
2. **Improved knowledge development.** Students are responsible for managing their pre-class learning, promoting the development of self-directed learning skills. Additionally, students repeatedly engage with the content in different ways before, during, and after class, enhancing information retention. The increase in active learning activities in the classroom also allows for the development of higher-order thinking skills and a deeper understanding of the content.
3. **Personalised learning.** On-demand videos allow students to learn at their own pace before class, and review challenging concepts as required after class. This pre-class material is typically accessible from anywhere, and this flexibility is especially helpful for students who must miss a class or need additional review.

Here, it is important to note that the benefits of the flipped classroom model depend heavily on its implementation. Some of the challenges associated with implementing the flipped classroom model, some specific to the first-year university context, include (McCarthy, 2016; Rotellar & Cain, 2016; Saterbak et al., 2016; Akçayir & Akçayir, 2018; Tomas et al, 2019):

1. **Low learner maturity.** As first-year students are dealing with the challenging transition from high school to university learning, they may not be used to self-directed learning and may struggle to take responsibility for engaging independently with the pre-class resources. Some students may struggle to balance their workload across multiple subjects, leading to incomplete preparation. They may also be resistant towards new instructional approaches, especially if they are already accustomed to more traditional modes of instruction.
2. **Quality of learning resources.** High-quality learning resources are key to the success of the flipped classroom model – these include both pre-class material as well as their corresponding in-class activities. Any increase in student engagement is highly dependent on these being well-designed, interesting, comprehensive, and constructively aligned. Here, any pre-class material should not be provided in a vacuum and should instead be properly signposted and scaffolded so that students have clarity around what is expected of them (especially important for first-year students).
3. **Heavy teaching workload.** The preparation of effective pre-class material and their corresponding in-class activities can result in an increased workload for instructors, at least in the initial stages of implementation. Studies have reported that the preparation of flipped classroom material may take up to six times longer than traditional classroom preparation.

This paper explores the implementation of the flipped classroom model in Engineering Technology and Society (ETS), a large-scale first-year subject that aims to introduce students to the world of engineering. The subject is transdisciplinary, with four interrelated modules centred around engineering-related professional skills, fluid mechanics, water disinfection, and image processing. Each module lasts between two to three weeks and consists of a set of constructively aligned lectures and workshop sessions. The subject adopts a “just-in-time” approach, where core concepts discussed in lectures are directly applied by students in workshop-based activities the following week. These activities help scaffold a semester-long real-world design project that requires students to work in teams to design a water pumping, disinfection, and distribution system to reliably supply potable water sourced from an underground well to a remote community. The overarching goal of introducing the flipped classroom model here was to increase student engagement and their overall understanding of the subject content. This would be achieved through repurposing scheduled lecture time for hands-on collaborative problem-solving and live coding sessions, aligning well with the applied nature of engineering. Survey-based student feedback was analysed quantitatively and qualitatively to provide insight into how the implementation might be improved in future runs of the subject. The findings here are relevant to instructors seeking to incorporate flipped classroom elements into similar large-scale first-year university subjects.

Implementation

Research Study Design

Table 1: Survey questions and responses. Short text identifiers (for questions) and numerical scores (for responses) are shown bolded within square brackets where relevant.

#	Question	Responses
1	Have you had any experience with the flipped classroom approach prior to ETS?	Yes/No
2	I watched the flipped videos ahead of each week’s lectures.	Always **[5]** Almost always **[4]** Sometimes **[3]** Almost never **[2]** Never **[1]**
3	I am confident with the concepts covered after watching the videos, even before attending the lectures that reference them. **[Concepts Before]**	Strongly agree **[5]** Somewhat agree **[4]** Neither agree nor disagree **[3]** Somewhat disagree **[2]** Strongly disagree **[1]**
4	I am confident with the concepts covered after both watching the videos and attending the lectures that reference them. **[Concepts After]**	
5	Overall, I found that concepts were explained well in the videos. **[Well Explained]**	
6	Compared with the traditional lecture mode, the flipped classroom approach improves my learning. **[Improves Learning]**	
7	I would like to see the flipped classroom approach implemented in other subjects. **[Other Subjects]**	
8a	Use the following sliding scale to indicate your preference for the flipped classroom approach.	Scale from Not preferred **[1]** to Preferred **[10]**
8b	Use the following sliding scale to indicate your preference for the traditional lecture mode.	
9	What did you like best about the flipped classroom approach?	<Free Response>
10	What could be improved in the flipped classroom approach?	

In Semester 1 2023, ETS had 400 students and was co-taught by two lecturers, with the primary author responsible for the Water Disinfection (Weeks 5 to 6 of the semester) and Image Processing (Weeks 8 to 10) modules. The research study was therefore designed around these two modules, designating the instructor as a control variable. Here, the Water Disinfection module was delivered traditionally while the Image Processing module was flipped. Students were informed that these modules would be delivered via different instructional formats in the introductory lecture (Week 1) and again towards the end of Weeks 4 and 7. The flipped classroom model, its benefits, the rationale behind introducing it in the subject, as well as the design of this study were also discussed in the introductory lecture. At the end of each relevant week with flipped content, a reminder about the required pre-lecture material for the following week was sent out as a subject-wide LMS announcement. At the end of the semester (Week 12), consenting students completed an anonymous online survey (Table 1) to gather feedback on their learning experience with the flipped format compared to the traditional format.

Development of Flipped Classroom Resources

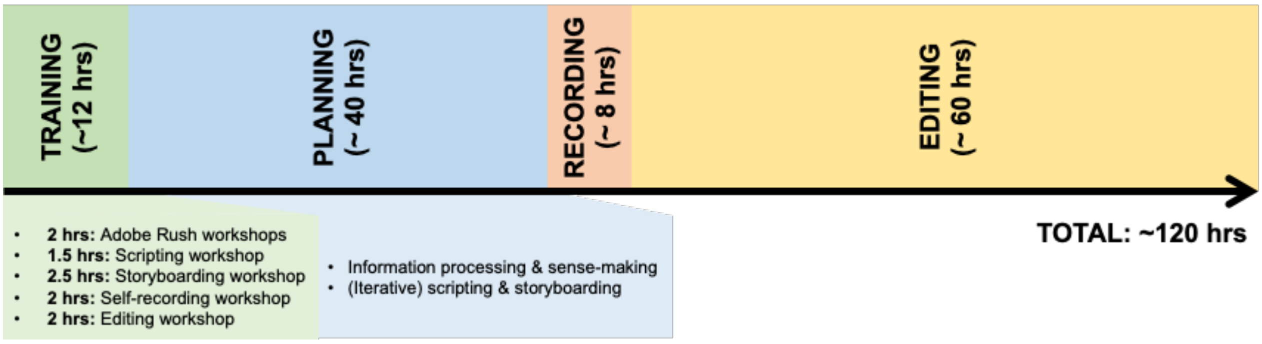

Figure 1: Pre-lecture video production process and timeline.

Pre-Lecture Videos

The bulk of the development effort revolved around the production of pre-lecture videos (Figure 1). The video production process initiated with a series of consultations and workshops with the University's Learning Environments team. These equipped the primary author with key skills and knowledge around video production, namely the setup of narrative arcs, storyboarding, scripting, video and audio recording, Creative Commons databases for stock images/videos, as well as video editing within Adobe Rush. This was followed by a relatively long planning phase, where the module's previous traditional-format content was critically evaluated and distilled down to a set of ten fundamental concepts, each to be covered in a pre-lecture video. In line with recommendations from the literature (Rotellar & Cain, 2016; Saterbak et al., 2016), care was taken to ensure that these concepts could be explained in an interesting (through thought-provoking examples and/or eye-catching visuals, for example) and concise (sub-seven minutes) way. This was achieved through co-temporaneous and iterative storyboarding, scripting, and sourcing of relevant accompanying visual content through Creative Commons databases such as Pexels.

The recording phase commenced upon finalisation of all storyboards and scripts. To ensure high-quality audio, recording was completed in a soundproof recording pod equipped with Rodecaster Pro microphones and Beyerdynamic DT770 headphones. Accompanying video footage was captured using Quicktime Player on a 2021 MacBook Pro at maximum quality settings. The editing phase was the final and most time-consuming phase. This was done in Adobe Rush and involved the integration of captured raw audio and video with visual content identified during the storyboarding process. University-branded motion graphics templates were also incorporated here, providing the pre-lecture videos with a consistent and professional aesthetic.

Scaffolding Content

McCarthy (2016) and Tomas et al. (2019) advise that pre-lecture videos should not just simply be made available to students via the University's Learning Management System (LMS). Instead, they should be introduced in a way that provides clarity around the intended sequence of learning (Table 2, which also includes echo360 analytics). This is especially true for first-year subjects associated with low learner maturity. In line with this, three separate pages were set up within the University's LMS, each corresponding to a week within the Image Processing module. Each page was designed to feature the following scaffolding elements, prescribing the recommended sequence of learning:

- **Intended Learning Outcomes.** This clearly lists the skills and knowledge that students should be expected to master after completing the week's content – this includes not just the pre-lecture videos, but also any accompanying in-class activities.
- **Pre-Lecture Videos.** For a seamless user interface, all pre-lecture videos for the week are directly embedded within their relevant page. Each video is also accompanied by a short (two- to three-sentence long) description of the concepts it covers. This allows students to quickly identify the content of each video should they need to revise specific concepts.
- **Practice Quiz.** Each page ends with a short unassessed practice quiz that students can use to check their conceptual knowledge after watching the pre-lecture videos. Quizzes are set up with unlimited attempts to encourage students to revisit the pre-lecture videos and patch up any gaps in knowledge if required. They are also designed to feature only questions that are conceptual in nature, with no calculations required.

In-class Activities

During the planning phase of the video production process, example problems that featured in the previous traditional content were excluded from the pre-lecture videos, which were designed to tightly focus on concepts. These problems were instead repurposed as interactive in-class activities, with adjustments and expansions where relevant. Due to this module's heavy focus on programming, most of these activities involved live hands-on collaborative coding. Here, the instructor worked with students to manually code possible responses to each problem from scratch. A Socratic method was adopted, where students were encouraged to suggest possible ways forward and to explain the rationale behind their suggestions to their peers. At times, these led to debates and discussions, and even the exploration of deeper concepts tangential to the presented problems. From an instructor's perspective, students enjoyed this more organic instructional style as they were able to steer the direction of the in-class activities by engaging with the content and asking interesting questions, providing them with a strong sense of ownership of their learning.

Table 2: Intended learning sequence & echo360 viewing analytics for the Image Processing module.

Week	Pre-Video	Pre-Lecture Videos (Duration in mm:ss)	Post-Video		Pre-Lecture Views		Total Views		Average Play-Through (%)
					No.	%	No.	%	
7	• Pre-lecture content reminder • Intended learning outcomes	Introduction to Digital Images (05:39)	Practice Quiz		121	30.3	240	60.0	78
		Basic Image Manipulation (04:38)			112	28.0	234	58.5	81
		Image Masking (04:15)			105	26.3	230	57.5	80
8		Digital Cameras (04:41)		Week 8 in-class activities	138	34.5	193	48.3	82
		Calibration (02:55)			137	34.3	189	47.3	91
		Image Filters & Convolution (05:45)			128	32.0	198	49.5	81
9		The if-else Statement (03:16)		Week 9 in-class activities	112	28.0	164	41.0	85
		Loops (04:52)			108	27.0	167	41.8	80
		Functions (04:52)			105	26.3	157	39.3	84
		Video Processing (03:15)			105	26.3	152	38.0	86
10				Week 10 in-class activities					

Outcomes and Discussion

206 complete student responses were received for the survey questions presented in Table 1, for an on overall response rate of 52% (cohort size: 398). Quantitative analysis was performed on this data, with the results summarised in Figure 2. 68% of the respondents had no prior experience with the flipped classroom model, with the remaining 32% having encountered it in their previous studies. Based on this, the data set was segregated into two groups: respondents with versus without prior experience with the flipped classroom model. Within each group, responses were then analysed based on the level of engagement with the pre-lecture videos (Question 2). For Question 8, preference ratings for traditional versus the flipped classroom approach were recast as a simple ratio for ease of analysis (i.e., quotient of 8a rating by 8b rating). Scores of above or below 1 therefore correspond to preferences for flipped or traditional teaching, respectively.

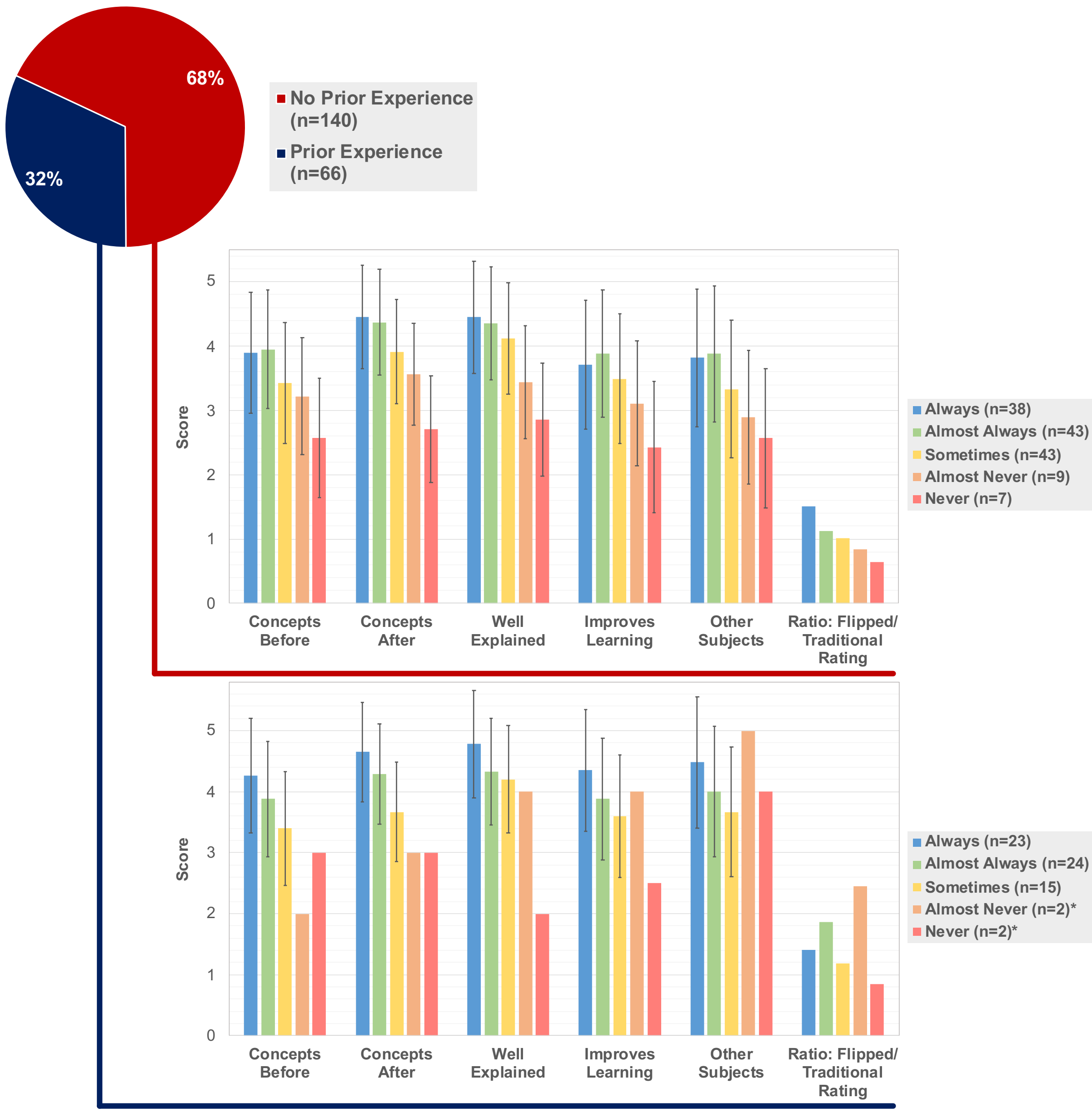

Figure 2: Quantitative analysis of survey data. Pie chart indicates students with versus without prior experience with the flipped classroom model. Bar charts summarise average ratings for responses to questions in Table 1, with error bars indicate standard deviations (*error bars not shown for sub-groups with low sample size).

Table 3: Thematic analysis of responses to Question 9: "what did you like most about the flipped classroom approach?". Grammatical errors in the responses have been rectified for clarity.

Theme	Sub-Theme	Comments
Increased student engagement	Interactivity	The flipped classroom approach for Image Processing is very helpful overall and very well-executed. The hands-on emphasis in the lectures (MATLAB coding and the live questioning) is quite unique to this subject and is extremely helpful in both keeping me engaged in lectures and understanding the concepts much better than just working through a problem set.
		The engagement provided within the flipped classroom model allowed for a much more enjoyable experience within lectures. The added interaction allowed many ways to learn. Instead of consulting Stack Overflow or the MATLAB forums, the lecturer went through things instead. This may not have saved time, but it has made it more enjoyable to learn MATLAB.
		I like that the lectures are actually interesting and engaging because we get to do coding examples in class. It has actually made the lectures very fun and made me look forward to going to them. I also like how the videos are very short, yet take a lot of pressure off of going through heavy content in the lecture itself.
	Video Quality	The pre-lecture videos were very concise and well-crafted which helped make them digestible. They were short enough that you could hammer them out not too long before a lecture if you'd forgotten to watch them the night before, etc.
		I've had experiences with flipped learning where the pre-recorded videos are really long and so it's very time consuming to watch them, but the ones in this subject were very concise and presented the key ideas in a prompt manner.
		The videos were extremely easy to watch, fast and concise. It was extremely easy to understand the content fast.
Improved knowledge development	Scaffolding	The idea of introducing all the concepts that will be covered in the week before they're looked at in detail felt like it allowed me to understand those details better. The ~15 minutes I spent looking at the pre-lecture content each week ended up feeling like the most efficient learning time I'd spend for the whole week which was always a satisfying feeling.
		I had a better understanding of what I was learning in the lectures and the concepts felt more familiar to me.
		It helps me enhance my understanding before attending lectures so that I feel confident about my knowledge, and it helps me find it easier to fit in the class.
	Consolidation	It's usually not the ideas/background of something that I have trouble understanding, but rather the way to implement it or use it. The flipped classroom approach puts a lot more emphasis on that second part.
		I liked the short quiz that was done after the videos, as it helped consolidate the knowledge. I also liked how it enabled the lectures to have more examples than the Water Treatment component.
		The best part was being exposed to the content multiple times over a period of time (spaced repetition), which helped with knowledge retention. It was also great to do more practice/example questions with the guidance of the lecturer.
Personalised learning		It allows me to learn the concepts at my own pace. I find it impossible to keep up with new concepts during a live lecture, when I can't pause and rewind. It makes the in-lecture examples fun, not overwhelming.
		Having accessible pre-recorded short videos on important content was useful for both an introduction into each new topic as well as for reference when revising difficult areas.
		I liked that I could watch the videos at my own pace, and it felt like the lectures were more engaging rather than just being talked at. I liked how when watching the videos and there was something I completely understood, I could immediately just speed it up, and if I didn't get it I could just go back and rewatch.

As previously mentioned, the group with no prior experience was associated with consistently lower ratings for all survey questions. This was not surprising as it reflects student resistance toward new instructional approaches, which can be particularly significant in cohorts with low learner maturity. Interestingly however, the sub-groups that did attempt to engage (i.e., always or almost always watched the pre-lecture videos) provided similar ratings as the group with prior experience. Specifically, they found that the pre-lecture videos explained concepts well, that the flipped classroom model improved their learning, and there was ultimately a preference for flipped classrooms and seeing it introduced in other subjects. Conversely, the sub-group that did not attempt to engage (i.e. never or almost never watched the pre-lecture videos) continued to show a preference for the traditional-format teaching. This indicates that the flipped classroom model can be effective if students are willing to give it an opportunity, with this being largely dependent on how well it is implemented and scaffolded. Quite interestingly, the results indicate that the learning sequence of pre-lecture videos followed by hands-on problem-solving in class resulted in increased confidence in concepts across the board. This was the case regardless of prior experience with flipped learning or the level of engagement with the pre-lecture videos. Despite the lack of statistical significance, this quantitative analysis suggests that the flipped classroom model does benefit student learning, and that students who have engaged with this mode of teaching tend to prefer it, or are at worst indifferent to it. Future efforts should therefore focus on how best to encourage the more resistant students to give flipped teaching – or indeed any non-traditional instructional approach – a fair chance.

Thematic analysis was performed on 110 qualitative student responses received for Question 9, guided by the three themes originally presented in the introduction. This identified further sub-themes, which are presented in Table 3, along with aligned sample student comments. These represent aspects that students liked best about the flipped classroom approach, and that should be considered key focus areas during the implementation of flipped teaching.

Qualitative responses to Question 10 identified two main areas for improvement in future runs of ETS. Generalising, these would also be relevant to consider when implementing the flipped classroom model in similar contexts, i.e., large-scale subjects characterised by low learner maturity:

1. **Increased signposting for pre-lecture content.** Subject-wide announcements were sent out at the end of each relevant week to remind students to go through the pre-lecture content ahead of their corresponding lectures. However, some students remarked that these were insufficient and that they forgot to complete the content ahead of lectures. These students came to class unprepared and therefore found the examples confusing and unhelpful. The instructor would often have to spend time quickly re-explaining concepts that were already covered in the videos, causing some discontent in students who had put in the effort to complete the pre-lecture content (*"The repetition of content from the videos in lectures was annoying to someone who actually put the minuscule effort into watching the videos, but I understand the need for everyone to learn."*). Interestingly, students from both these groups suggested attaching small assessment weightings to the pre-lecture content to drive engagement (*"I found myself falling behind in watching the videos – possibly making watching the videos compulsory."; "I think the approach works fine right now, but maybe making the pre-lecture quiz assessed as a small part of the overall grade might ensure more students actually watch the videos before the lectures."*).
2. **Improved student literacy around instructional modes.** The subject's introductory lecture briefly discussed the flipped classroom model, its benefits, and the rationale behind introducing it in the subject. This was done to provide transparency and awareness around the decision to experiment with this instructional approach. However, several comments suggested a fundamental misunderstanding around both the applied nature of engineering and the flipped classroom model (*"Going to ETS lectures were kind of a waste of time because it was more application of concepts rather than teaching foundational knowledge."; "I prefer the traditional lecture model as my motivation to attend lectures was very low as no new content was covered and I didn't really find the examples too important to watch."*). A more in-depth discussion of hands-on problem-solving in engineering and how this pairs well with the flipped classroom model could be included in future runs – improved student literacy around instructional modes might improve engagement.

Overall, our analyses indicate that this initial implementation of the flipped classroom model in ETS has generally benefitted student learning and have helped identify specific areas for improvement. These align well with the "flipped learning continuum" model proposed by Tomas et al. (2019). In this model, the low learner maturity of first-year students means that some elements of traditional teaching should be maintained when flipping, such that students do not yet have full autonomy over their own learning. These include a higher degree of instruction around deliverables and concept delivery than might be expected in a fully-flipped classroom, as well as the use of assessment as a tool to drive student learning via improved engagement with the flipped content. The quantitative analysis suggests that students who engage with flipped teaching ultimately end up preferring it, and so these interventions might help persuade the more resistant students within the cohort. It would also be interesting to flip the Water Disinfection instead of the Image Processing module in future runs to eliminate any potential biases associated with each module's content, as well as to investigate the effects of flipped teaching on students' assessment results.

Conclusion

The initial implementation of the flipped classroom model in ETS has generally been successful, with proven benefits to student learning. Here, increased engagement via in-class interactivity and high pre-lecture video quality, improved knowledge development via enhanced scaffolding and consolidation, as well as the personalisation of learning were identified as key advantages of the flipped approach. The low learner maturity of this cohort resulted in some degree of resistance towards flipped teaching, coming primarily from students lacking prior experience with the instructional approach. Despite this, the data suggests that students within this group who do engage with the approach end up preferring it. Future directions should therefore focus on ways to encourage the more resistant students within the cohort to engage with the flipped material.

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