Implementation and evaluation of flipped learning for delivery of analytical chemistry topics

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INTRODUCTION

Traditional teaching methods are common in delivery of STEM subjects where little active student participation is observed[1]. Active participation, such as answering questions or problem-solving, often leads to more effective learning when compared to instructor-led lectures[2]. Moreover, a lack of active participation in the classroom regularly leads to a reduction in attendance and decreased engagement with the subject material.

Flipped learning, or the flipped classroom, is an innovative educational approach that has established itself in recent years as an alternative to traditional teaching methods. Most studies generally highlight the benefits of flipped learning, with the most significant being the ability to develop active learners [3-5]; however, others are sceptical, querying its efficacy in the lack of perceived gains in terms of grades[6] and resources needed to develop and deliver flipped learning[7].

There are many variants of the flipped classroom model of which the most common utilize a blended learning approach, with study material being provided to the students in advance of the class to enable them to actively learn the subject area prior to the formal class time. Class time then establishes an interactive learning environment where students engage in activities and problem-based learning materials that are instructor led[5]. Flipped learning has been widely applied in STEM subjects, notably in the delivery of physics, engineering, and mathematics [3,8,4], and its use in chemistry teaching is increasing, with various studies being published on the delivery of organic or general chemistry in this way[9-12,8,13-16].

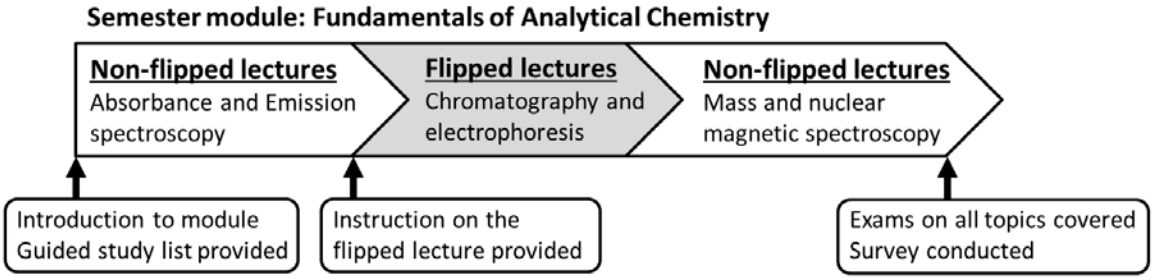
There are, however, few studies on the implementation of flipped learning in analytical chemistry, which leads itself to this format of learning due to the problem-solving nature of the discipline [17-19]. One such study utilized Prezi based

presentations plus guided study to provide greater scope on focussing on complex problems within the classroom[18], concentrating predominately on the presentation platform students utilized, but producing limited insight into the effectiveness of the complete flipped model. Another study compared flipped learning's effectiveness for teaching both general and analytical chemistry and found student attitudes were more positive towards flipped learning in analytical chemistry [17].

Our study focused on implementation and evaluation of flipped learning in a topic of an analytical chemistry within a module taken by biomedical scientists over a duration of 3 years. We compared the flipped learning approach to non-flipped lectures given within the same module. The comparison in the engagement and performance between the flipped and non-flipped sessions was evaluated.

STUDY DESIGN

The study was approved by the School's Ethics Committee. The flipped learning approach was delivered in a first semester fundamentals of analytical chemistry module to BSc(Hons) Biomedical Science students. Figure 1 shows the study design utilized, where one third of the way through the traditionally taught module, the lecturer conducted the flipped learning approach. Over the 3 years of the study, 290 students were exposed to flipped learning: during this time the average cohort age group, gender and first year higher education grade profiles were not significantly different between the years of study. Figure 1 also provides information on the topics that were delivered in the flipped and non-flipped learning approaches.



Class	Topic	Online lecture content	Workshop	Assessment
Year 1 73 students Year2 109 students Year 3 107 students	Chromatography and electrophoresis.	Three video lectures covering theory, instrumentation and explanation of the various forms of chromatography and electrophoresis	Problem-solving: Tasks were based measuring chromatography parameters, choosing the appropriate chromatography technique for a set of analytes and being able to predict the order of chemical separation. Conducted over 3 workshops	Exam: Questions based on elements of the workshops

Figure 1. Study design for the delivery of flipped learning within the analytical chemistry module and the content and assessment covered within the flipped section

IMPLEMENTATION AND EVALUTION OF FLIPPED LEARNING

At the start of the module, students were informed about the content covered within the module, the assessment, and the guided study material they were required to complete to support their learning for all topics. The guided study materials were made available through the virtual learning environment (VLE), Blackboard©. Students were also informed there was a threshold attendance requirement of 80 % if they needed to re-sit the assessment if they failed on the first attempt. Initially, students were given a series of conventional face-to-face lectures on the topic of absorbance and emission spectroscopy (6 hours), then the flipped learning section of chromatography and electrophoresis (6 hours), followed by a further non-flipped teaching session on mass and nuclear magnetic spectroscopy (6 hours). At the end of the entire taught content, students were given a survey to complete (see Figure 1).

For the non-flipped session, the classes consisted of lectures for 50 minutes with which contained some examples of problems that were relevant to the examination. They were also provided with a revision session to work through examples of unseen examination questions in the classroom. Students were notified about the flipped learning resources and how to access them a week prior to the delivery of the chromatography workshops. They were also told that they would be required – as guided independent study – to review the online material prior to the face-to-face problem-solving workshop class.

The self-study e-learning package was set up on the VLE, which consisting of video lectures created using Camtasia® and an online blog to allow students to post questions or flag up areas of difficulty. All students were encouraged to answer questions posed on the blog by their peers, with the lecturer moderating and providing responses, where necessary, for a fixed 2-hour period each day. The video lectures were provided in approximately 30-minute segments for ease of access. This is generally larger than most suggested timescales for online video content, however provided appropriate timescales for specific topics. The style of video lectures were based on studies that provided insight into good video lecture construction[20,21]. All content within the VLE remained available for the duration of the module.

The first 15 minutes of the face-to-face problem-solving workshop were dedicated to any frequently occurring questions or topics highlighted in the online blog or send via email. The remainder of the session was dedicated to a problem-solving activity as indicated in Figure 1. The lecturer worked through one example of the activity with the whole class, after which, the classroom which was sat on tables consisting of 8-10 students, working in smaller groups to conduct the activity (3-4 students). The lecturer asked one student on the table who felt confident with the topic to act as mentor for the table. This approach was similar to that adopted for the SCALE UP programme[22]. During the workshop sessions, the lecturer checked if each group had understood the material and facilitated learning with the aid of the student mentor. At the end of the module, students were asked to complete an online survey to evaluate the effectiveness of flipped learning when compared to the traditional lectures within the module.

Students were asked to provide constructive, evaluative feedback by completing an online survey provide at the end of the taught lectures and was available up to the date of the module exam. The survey was designed using SurveyMonkey® with a mixture of questions eliciting Likert scale or free text responses. Data was also sourced from the VLE's learning analytics which showed how often and for what duration individuals accessed the material, as well as class registers which allowed comparisons of attendance between the non-flipped and flipped lectures. Finally, examination grades were compared from topics taught using non-flipped and flipped learning within the module.

STUDENT ENGAGEMENT WITH FLIPPED LEARNING

To evaluate student engagement, we examined the number and duration of views of the online video lecture on chromatography theory, and attendance at its corresponding problem-solving workshop. Figure 2 shows the degree of engagement students had with this topic over the 3 years of this study. We also reviewed the number of views of this video lecture by students by hours of the day over the same time period (Figure 2A). These significantly increased from 10 am to 8 pm ($p<0.05$). This timeframe covered the 2-hour slot when students could post questions/issues on the online blog and received responses from the lecturer (Figure 2A). This also suggests that students learn in timescales beyond the normal timetable and carry out

their studying during the evening. This may be explained by some students needing to work part time to support their studies and having limited time for study during the normal working day.

The success of flipped learning is based on engagement with the online content before face to face contact. This is essential to make the 2-hour problem-based workshops effective learning environments. Figure 2B shows that students studied the online lecture material prior to the workshop, and this was consistent for all three years of this study. This indicates that the students were aware of the importance of conducting the guided study and/or felt the pressure of being left behind when compared to fellow peers who did engage with this learning approach. In one particular cohort (year 2), we observed a significant number of students who also engaged with the learning content after the problem-solving workshop, implying reflection on the learnt content.

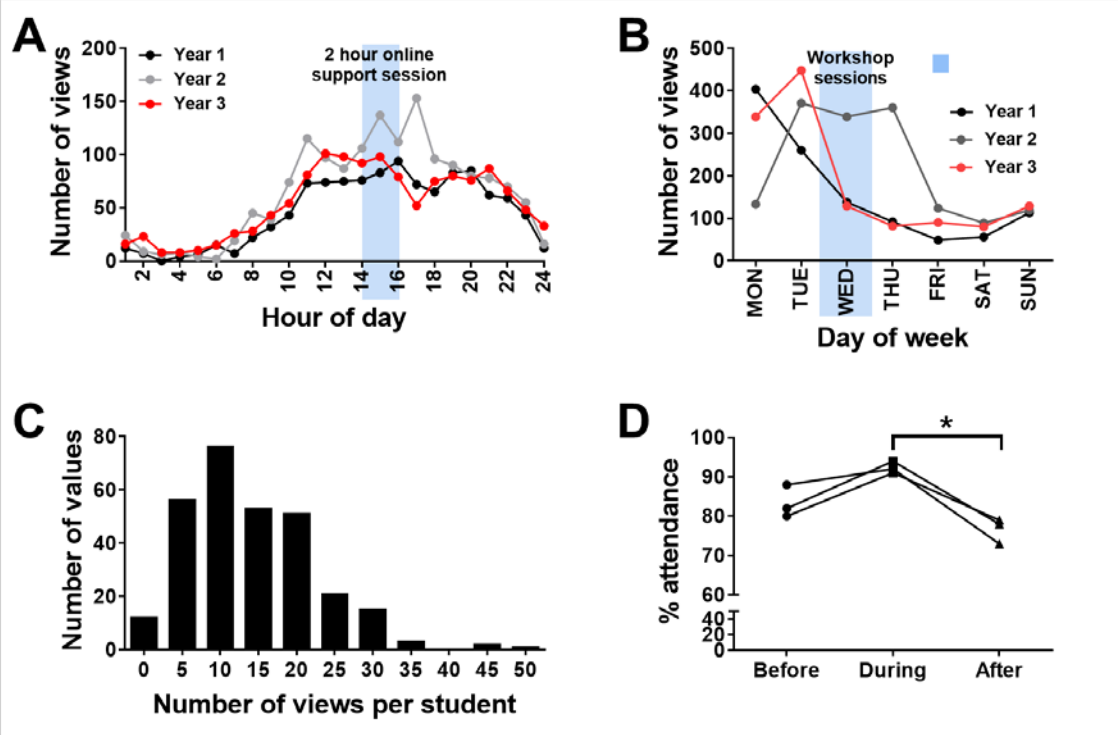


Figure 2. Engagement with flipped learning content for material on chromatography theory. (A) number of views per hour of day, (B) number of views per day of week, (C) The number of views per student for one single online video prior the taught workshop over 3 years and (D) changes in attendance in flipped and non-flipped sessions.

When examining the average number of views per student over the 3 years for the chromatography theory video lecture content, we observed that the majority of the

students looked at the content (Figure 2C): only 4 % of the students did not engage with the online videos. The median response was 13 views of the online video. The average time per view of the chromatography theory video lecture was 13 ± 4 minutes (n=278). This viewing time is similar to what is indicated for an appropriate time for video content online[23]. There was no significant difference in the number of views and the average time per view for all the other video lectures provided as part of the flipped learning study. As the online lecture content (approximately 30 mins in duration) was required to be reviewed prior to the lecture, it is most likely that the majority of students watched the entire online material in very short bursts prior to the workshop. This suggests that the students are engaged with the flipped learning model and have actively participated in their learning, as they are reviewing the online material. The fact that they engage with the material in multiple burst of brief time scales suggests a preference to learn material in small packages which, as suggested by the work of Abeysekera and Dawson[24], would reduce and spread cognitive load and provide time for reflection.

Figure 2D shows the differences in the attendance at the flipped and non-flipped classes. There was no significant difference in the attendance at the start of the module and the flipped session; however, there was a significant reduction in the attendance of the non-flipped lectures delivered after the flipped sessions ($p<0.05$, n=3). Although not significant, there was a slight increase in the attendance during the flipped learning session when compared to when the module started. This change in attendance may be due to increased engagement in the flipped learning module; however, it could also reflect a perception that a more exciting approach of lecturing or content is to be delivered. The enhanced level of engagement may also be due to that fact that students could feel left behind in the problem-solving workshop sessions. The reduction in attendance post flipped lecture may be due students deciding to focus on assessments, feeling that they may have met the threshold attendance requirement.

USEFULNESS AND STATISFACTION OF THE FLIPPED LEARNING MODEL

We received 81 survey responses from the 290 students (28 %) who studied the module over 3 years. Figure 3A shows the relative usefulness of each of the delivery aids utilized for flipped learning. We used a Likert scale system, where 5 was rated as most useful activity to aid their learning of the topic. For the online blog, the mean

response was 3.08 (2.87 and 3.29; lower and upper 95 % Cl of mean, n=64). For the online video lectures, the mean score was 4.15 (3.91 and 4.39; lower and upper 95 % Cl of mean, n=61). Finally, for the face-to-face problem-solving workshops, the mean score was 4.51 (4.36 and 4.65; lower and upper 95 % Cl of mean, n=73). Students found the taught problem-solving activities in the workshops to be more useful than the online blog ($p<0.001$, n=64-73, Tukey test) and the video lectures ($p<0.05$, n=61-73). From the electronic components available, students found the online video lectures to be more useful than the blog ($p<0.001$, n=61-64). These findings are as expected, as the problem-solving workshops engage students in activities, which are regularly seen to be more stimulating than conventional lectures[25]. There is often less time to conduct problem solving learning activities in analytical chemistry classes as classroom time is dominated by the need to make sure the students understand the underlying theory. The online lectures were also deemed to be highly successful, possibly because they were short, and allowed students to learn in at their own pace.

The online blog split opinion with half of the students enjoying it and the other half disliking it. There are two factors which probably account for this: firstly, that students want an immediate response to a blog entry, which cannot be easily offered due to them posting at various times. Secondly, many students were not keen for their peers to see their posted questions and therefore they emailed the lecturer with regards to areas of concern they would like to have covered in class. During the flipped learning activity, the staff member received 45 emails. This further highlighted that students were interested in directing their own learning.

Figure 3B shows the students' degree of satisfaction with the flipped learning approach for delivery of analytical chemistry when compared to conventional lectures. We found that 95 % of the students were satisfied to some degree with this format of learning. This suggests that flipped learning can be an effective educational approach for delivery of analytical chemistry as shown for other areas of chemistry[8,5].

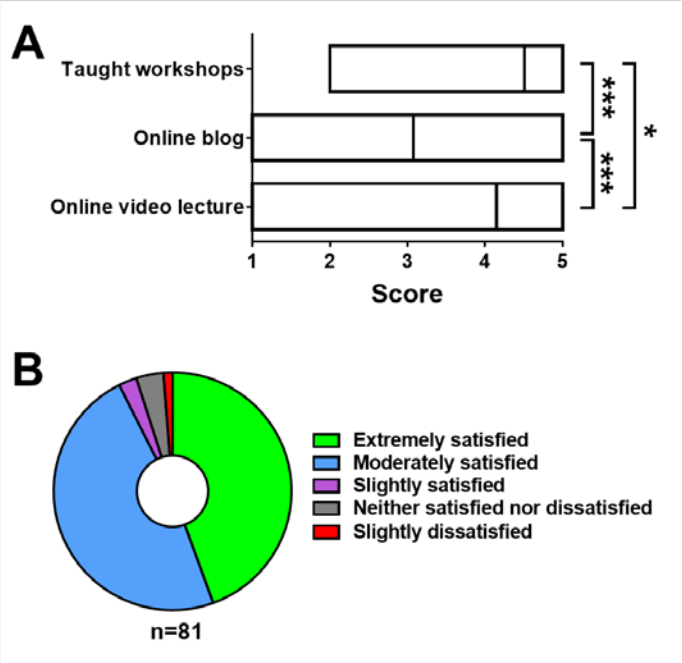


Figure 3. Usefulness (A) and satisfaction (B) of the activities utilised for delivery of flipped learning. Usefulness was monitored using a Likert scoring where 1 was considered not useful and 5 considered extremely useful.

STUDENT PERCEPTION ON FLIPPED LEARNING

Table 1 shows show the students' perceived strengths of flipped learning. The major recurring comments observed from students were that video lectures can be reviewed many times (particularly mentioned by international students), and that they could check/practice their understanding and knowledge of the learnt video material with the lecturer in the taught problem-based workshop. Other key comments are all indicative that this approach to teaching makes students engage more actively in the learning process.

Table 1. The perceived strengths of flipped learning for delivery of analytical chemistry

Comments mentioned	Count
Can review as many times as desired (international students particularly liked this)	16
Learn at own pace/personalized method	6
Can check understanding/practice material with lecturer	23
Provides a deep understanding of material	9

Encourages more reading outside face to face time	3
Learned more as had to apply the knowledge	8
Take in far more than just listening to a lecture	4
Gives me more confidence in applying the principles in real life scenarios	1
Encourages you to read outside of lectures as you will be tested on knowledge in the next lecture which is beneficial to other subjects as well	6
Easier to go through the material and write your own notes	7
The student is more in control; not taught at, or spoon-fed the content of the lecture.	4
Problem-based workshops provide a forum for debate to chew over the applications.	8

Table 2 shows what students perceived as weaknesses in using flipped learning to deliver analytical chemistry. In comparison to the strengths, there were less weaknesses raised by the students. The key issues are associated with students who failed to understand aspects of the online materials and how this can make it hard to understand the problem-based workshop. Other issues are all focused and associated with students having to put in more effort and motivation to learn the study materials independently. This aspect meant that students also found this style of learning forced them to take ownership of their time management, and some found this particularly challenging.

Another limitations of flipped learning, is that students are unable to have any aspects of the video lecture clarified as they watch it in their own time. Within our study, we tried to overcome this issue by employing the fixed time slot for interaction with the online blog and dedicating the first 15 minutes of each workshop to cover any material students flagged as difficult either via email and/or the blog.

Table 2. The perceived weaknesses of flipped learning for delivery of analytical chemistry topics

Comments mentioned	**Count**
Need to be organized	3
If others don’t do work in advance it slows the whole class	5

If online material is not understood it can be hard to follow the class exercises efficiently	12
Time-consuming	3
Self-motivation is lacking to watch material outside class	6
I don't learn this way	3
Audio quality is poor in places	2
More work to do in our spare time	6
Coming to lectures pointless	2

ENHANCEMENT IN PERFORMANCE

Within the module assessment, students are required to answer 2 questions from 3 options in the examination paper. Two questions in the exam were from topics covered using conventional lecturing and one question was taught using the flipped model. Comparisons were only obtained where students had answered one question covered by the flipped approach and one question taught by conventional lectures. Over the duration of 3 years, the average grade out of 20 marks for the flipped taught content was 12.6 ± 4.2, which significantly reduced to 9.4 ± 5.8 ($p<0.001$, Students t-test, $n=213$) for the non-flipped marks. This suggests there was an average 16 % increase in the marks for the content delivered by flipped teaching. This improved performance could be due to the flipped learning approach enhancing student learning, but may also include other factors, such as students finding the topic of chromatography more interesting or easier than spectroscopy; or that the format of flipped learning made students feel more positive about the subject area compared to those that were delivered traditionally.

BENEFITS OF USING FLIPPED LEARNING FOR DELIVERY OF ANALYTICAL CHEMISTRY

There is no doubt about the effectiveness of flipped learning in education of general and organic chemistry [10,8,13-16]. What is less evident, as there are only a few studies [18,17], is if analytical chemistry is well suited to the flipped teaching model. This study suggests that flipped learning can be an effective model for teaching analytical chemistry in single topics and potentially entire modules. This approach

provides the means for students to take active responsibility in their learning, which they can do at their own pace and conduct problem-solving activities within the classroom environment which underpin the discipline of analytical chemistry.

CONCLUSIONS

Analytical chemistry is a discipline that is focused around problem-solving and therefore is ideally suited to flipped learning. We have successfully implemented and evaluated the effectiveness of flipped learning for the delivery of analytical chemistry content. There was high engagement with all the flipped learning resources except the online blog. Our metric based data is suggests that 96% of students would have studied the online video lectures for sufficient duration to actively learn the content. Students highlighted that the online video lecture provided flexibility in when they can learn the material, and at a pace to suit their individual learning needs, which spreads and reduces cognitive load. The students found the problem-based workshops the most useful element, due to the interactivity in the classroom environment, but they were not so keen on the online blog as a means of asking questions on aspects of the electronic lecture they did not fully understand. The students were satisfied with the flipped learning when compared to conventional lecturing. Therefore, flipped teaching can be utilised for the entire course. Overall these findings suggest that students took an active responsibility towards their learning and were satisfied with being able to learn at their own pace and conduct problem based activities in classroom sessions. The combination of such activities provides a means to spread cognitive load when learning a topic and increasing germane load based activities associated with that learning, which provide in-depth understanding.

Conflict of interest

The authors declare that they have no conflict of interest

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