Adopting a flipped classroom approach for teaching molar calculations to biochemistry and genetics students

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Abstract
The flipped classroom is a relatively new active learning pedagogical intervention, gaining popularity as a blended learning methodology. The flipped classroom comprises two distinct parts, directed learning carried out at the student's own pace away from the classroom and an interactive, class-based activity encouraging problem-solving and experiential learning. This research presents a one-year study to measure student performance and perception towards a flipped classroom approach to teaching core biochemical calculations to first-year undergraduate biochemistry and genetics students. A post-task questionnaire showed an overall positive student perception with an associated significant improvement in the end of module summative assessment. These results suggest that this teaching approach offers some advantages over more traditional teaching pedagogies.

Introduction
The origins of the flipped classroom are typically attributed to Lage, Platt, and Treglia who coined the term the 'inverted classroom' [1] although the idea of making material available to students in advance of class was also proposed two years earlier by Walvoord and Anderson [2]. Traditional higher education teaching tends to follow the lecture-coursework format, which promotes lower order thinking skills, as defined by Bloom's Taxonomy [3], during class time and higher order skills at home. The flipped classroom methodology inverts this, with preparatory material being made available to students in advance, so that during the face-to-face class time students can engage with investigative learning to solve problems. Therefore, lower order thinking skills such as remembering and understanding occur outside of class time at the student's own pace, while the higher-order active learning skills like analysis and evaluation take place in class with support from peers and guidance from the instructor [4,5]. There is evidence that using preparatory material followed by face-to-face instruction increases student understanding and engagement with these higher order thinking skills [6,7], which is reflected in an improvement in assessment scores and student satisfaction [8]. The inefficiency of passive, lecture-based transfer of knowledge has been suggested to result in poorer student engagement, understanding and, importantly, retention of knowledge [9], which implies that active learning approaches have potential advantages for students. The recent, gradual shift away from teacher-focused pedagogies to a more student-centred approach has seen an improvement in student learning outcomes across multiple disciplines, including biochemistry [10,11].

The flipped classroom is becoming increasingly popular in science, technology, engineering and mathematics (STEM) subjects, indeed, a growing body of literature suggests an increased use of the flipped classroom methodology across post-secondary education; a recent study carried out in 2015 found that 29% of academics had adopted the flipped pedagogy and a further 17% had tried the approach [11]. One potential barrier to implementing this methodology is the misconception that there is a one size fits all approach to this pedagogy [12], whereas in fact the opposite is probably true and there is no clearly defined system that adequately describes the implementation of this teaching strategy [13]. As with all teaching pedagogies there are also practical limitations that need to be considered including student motivation and technological issues. Students may not have experienced flipped learning before and this less familiar setup can be daunting as the success of the flipped classroom approach, as stated by Johnson, is heavily reliant on students having the motivation and self-discipline to engage with the pre-class material [14]. There may also be resistance from students if they perceive themselves responsible for their own learning, as opposed to the more passive transmission of information to the student in a didactic lecture [15]. However, these concerns can largely be alleviated by careful explanation of the potential benefits of the approach to students prior to exposing them to this methodology [16]. It is also important to note that a small minority of students, with an aversion to technology, may be disadvantaged by this approach, although studies have shown that a majority of learners welcome the use of technology in education [17]. The lack of instructor contact can also be perceived as a weakness of this approach, students are unable to ask immediate questions, which may lead to confusion and disengagement with material. Although students do have the ability to clarify misconceptions during face-to-face sessions, it is possible that students will have forgotten the precise issue that caused them confusion [14].

In this study, the adoption of the flipped classroom approach in a first-year undergraduate introductory calculations course, designed to give students experience of molar calculations, is described. Data collected from an end of module summative assessment and anonymous questionnaires were analysed to assess student performance and satisfaction.

Methods

The flipped classroom approach was implemented in a first-year small group teaching based module, with 8 tutor groups each with 12 students (n=96), running over one ten-week semester with a total of 6 hours face-to-face instruction and further work outside the class in the form of watching videos and completing example questions. The course is spread across the first 10-week teaching block to provide students with ample opportunities to review questions and to align the taught material with laboratory-based classes in parallel modules that use the calculation techniques. The course introduced students to the core concept of molar calculations, revising some material covered at secondary level, but also introducing several new ideas that students will require during the course of their degrees. The module is compulsory for all biochemistry and genetics students; however, this was the first year that the content of this course was made available to genetics students following a review of student feedback and module alignment. As a result, some students taking the course may not have done secondary level chemistry, as this is not an entry requirement for the genetics programme. Therefore, the course had to be designed to teach the fundamentals of the mole, molarity and simple dilutions to these students, with this material acting as a revision opportunity for those students with secondary level chemistry. This introduction gave students confidence in their ability before introducing new concepts including percentage weights and volumes, advanced dilutions including serial dilutions and sequential dilutions, unit conversion, the principles of spectroscopy and the use of this technique to determine concentrations and pH, including the Henderson-Hasselbalch equation.

In previous years this material was delivered in a small group teaching environment through a didactic lecture with a series of homework questions that were attempted by the students in their own time. Students then attended a further small group teaching session where they were able to go through these questions with their peers and a tutor. A final set of homework questions were provided at this tutorial and the process was repeated. To switch this to a flipped approach a series of online videos were prepared using PowerPoint (Microsoft) and Camtasia (TechSmith) software covering the course content. The videos introduced the core concepts accompanied by worked examples of the types of questions the students would encounter in the summative, end of module assessment. A series of concept-checking homework questions that did not contribute to the overall module mark were embedded in the videos but left unanswered to allow students to check their newly acquired knowledge. The videos and transcripts were made available to students via the University's Virtual Learning Environment (VLE), Blackboard Learn.

The module ran over ten weeks, with videos being made available every third week (weeks 1, 4 and 7), with approximately 20 minutes of videos made available each week. Week 1 covered moles, molarity and percentages, week 4 unit conversions and spectroscopy and week 7 dilutions and pH, with the material taught in this module aligning with the knowledge required for laboratory practical sessions being undertaken in a parallel module. Students were asked to watch the videos and attempt the concept-checking questions prior to attending a face-to-face tutorial the week after each set of videos were released (weeks 2, 5, 8) to discuss the homework questions in pairs or groups and then to attempt further formative problems of increasing complexity, led initially by peer-to-peer instruction and subsequently with instructor guidance as required to clarify any misconceptions. Further formative homework questions of a more advanced nature were provided online after these sessions for students to prepare for the following weeks (weeks 3, 6, 9), where the peer-led discussion was again used as an instruction method. As this module is provided bilingually, both videos and tutorials were also provided in Welsh. A final summative assessment, comprising 26 online questions of increasing complexity was completed in week 10 at the end of the course; the test was open book with no time limit and contributed 35% of the final module mark. The summative assessment was identical for all years reported in this study. The weeks and exercises are summarised in table 1.

The completion of the flipped classroom material and summative assessment was compulsory with all student data included in the analysis. Completion of the feedback questionnaire was voluntary; students were not offered any incentive to complete the questionnaires and were able to withdraw their participation at any point without penalty. The study was approved by Swansea University Medical School's Ethics Sub-Committee (2019-0039).

Statistical Analysis

The primary research question was whether the intervention had a measurable impact in overall performance in the online assessment. This was answered by comparing the performance of the intervention cohort with the previous academic year, who were taught in a more conventional format.

Secondary research questions were to determine the level of student satisfaction with their experience, and their overall perception of the flipped classroom approach. This was informed through an anonymous questionnaire, given to students following the last face-to-face teaching session, which comprised an approval score, based on a 5-point Likert scale, and a free text response.

Statistical analysis was carried out using SPSS, using appropriate methods, and a 5% level of significance. A two-tailed t-test was used to assess changes in student performance. Performance on individual questions was compared using Chi-Square analysis. Student satisfaction with the approach was determined using two-tailed binomial analysis.

Results

Data Summary

The flipped material was made available to 96 students with 48 (50%) enrolled on biochemistry degrees (21 (44%) male, 27 (56%) female) and 48 (50%) on genetics degrees (21 (44%) male, 27 (56%) female). Forty-four (46%) students completed the voluntary questionnaire, 89 (93%) students attempted the online assessment. Summary statistics of student performance pre- and post- adoption of flipped approach are presented in table 2.

Student Engagement

The total number of views of the videos by week was analysed to calculate an estimated total viewing time and view per student (table 3). These data suggested that students were engaging well with the resources, accessing each set of videos on average 3 times.

Overall Student Performance

Analysis of the marks achieved for the summative online assessment revealed that there was a statistically significant difference ($p=0.025$; t-test) in the overall student performance for the whole 2018/19 cohort compared to students in the 2017/18 cohort, who did not have access to these videos, but were taught through traditional lectures followed by peer-instruction tutorials. (figure 1 and table 3). The recorded improvement was also educationally significant, with an estimated average increase of 7.1 percentage points (0.9, 14.3; CI 95%) in the intervention group. Furthermore, Glass' effect size value ($d=0.4$) suggests a moderate practical significance

As this was the first year that genetics students had participated in this module further sub-group analysis was carried out showing significant, or near significant, improvement over the previous cohort for both Genetics ($p=0.071$) and Biochemistry ($p=0.041$) students but, importantly, no evidence of a difference between these groups ($p=0.715$).

Individual question analysis

An additional chi-square analysis was performed to determine whether there was a significant difference in the performance on individual questions following the adoption of the flipped classroom. A comparison of the proportion of successful completions between students taught using the peer-led and flipped approach showed significant improvement in

5 of the 26 questions, based on a 5% level of significance, with increases in the student pass rate of 10-30%. Two further questions came close to significance, with p-values of 0.060 and 0.095 and associated improvements of 12% and 9% respectively. The questions used in the test were identical for both groups of students.

In total 21 of the 26 questions showed an overall improvement between the cohorts. While the small number of cases showing a reduction in performance indicates a fairly general improvement the very high increases in pass-rate in a handful of questions may suggest that the intervention is not always equally effective. No obvious pattern could be discerned in the intervention effect when the impact of question type or topic were considered.

Student Satisfaction

Forty-four out of ninety-six (46%) students completed the anonymous 5-point Likert scale end of module questionnaire. Results from all students that responded were collated and the percentage approval for the individual questions and free text responses analysed without correction for demographics. The results show an overwhelmingly positive response towards this teaching methodology with the overall percentage responses at each perceived level summarised in table 4. Binomial analysis showed high levels of significance for all questions ($p<0.001$ in all cases).

The overall summary of the questionnaire is provided in figure 2. Of particular note are the responses to questions 6 and 7, regarding confidence in the material before and after attending tutorials, which increased from 28.6% to 60.5% strongly agreeing. Question 8 also showed that 86.4% of students strongly agreed that attending the tutorials improved their understanding on the key topics.

Out of the 44 students completing the questionnaire, 19 (43% of respondents, 19.8% of total cohort) also provided free text responses. These responses indicated a very high level of approval of the intervention. In particular students appreciated the opportunity to explore their own responses compared to their peers and the supportive nature of the small group teaching. We include below a selection of typical answers to illustrate the positive response to the flipped pedagogy:

- “Everyone writing their answers regardless of right or wrong and exploring the calculations/where they went wrong.”
- “It is a very individualistic approach as it allows for a clear identification of my shortcomings, giving me an area to focus on.”
- “There is a chance to show methods of working out answers and to discuss any problems we had with difficult questions.”
- “The fact that we spent most of our time self-teaching and then were provided with an opportunity to ask questions.”
- “Having completed the work prior, so when arriving for tutorials I could focus on revision of where I went wrong/did not understand and ask relevant questions”
- “I really (like) the way that we are taught in a small group so we can feel ourselves more confident about asking and discussing”

Discussion

Student performance

As higher education strives to enhance the high-quality learning opportunities for students, the flipped classroom has been gaining traction in post-secondary STEM teaching [11] as an active learning pedagogy. In this study, a significant increase in overall cohort performance was observed with a positive shift towards marks in the higher degree classification boundaries. Biochemistry students showed a significant increase, whereas genetics students showed some improvement, but this did not reach significance. It should be noted that this was the first time that genetics students have been enrolled on this module and that A-level chemistry is not a requirement for entry onto the Genetics degree programme. Encouragingly, therefore, there was no significant difference between the overall performance of biochemistry and genetics cohorts. It will be interesting in future studies to correlate the attendance at face-to-face sessions with end of module performance and compare this to whether students come into the module with A-level chemistry. Overall these results suggest that active learning tasks before and during class has a positive impact on student performance. There is also the added benefit that active learning confers significant additional benefits to students from disadvantaged backgrounds and female students in traditionally male-dominated STEM subjects [18,19]. Students also made good use of the online resources, learning at their own pace and watching the videos multiple times.

Analysis of performance on individual questions showed that there was an overall positive improvement in 21 of the 26 questions with 5 of the 26 reaching significance and a further 2 that approached significance. It is not apparent why the performances on these questions in particular have improved so dramatically, but further investigation of individual student responses compared to previous years may shed light on this.

Responses solicited in the end of module survey suggested that students engaged well with the online material and had adequate time to prepare for the face-to-face teaching sessions. They also highlighted a benefit in attending the tutorials, feeling more comfortable with the material covered and were able to work more independently. The responses indicated that the instruction within the tutorial is still important, but with this approach, much of that learning occurs via peer-peer engagement. The tutor has a fundamental role to clarify misconceptions but acts much more as a guide to the peer-led instruction. The written comments from students showed high levels of satisfaction with the approach and support for continuing it, which is in agreement with other studies assessing the benefits of this pedagogy [10].

It is important to note that this preliminary study represents results from one year's cohort of students over a relatively short (10-week) course. Natural fluctuations between cohort ability may contribute some of the effect observed in this study and further investigation will be required to determine whether the flipped classroom approach produces sustained improvement in student performance. It is possible that students who responded to the questionnaire are those that engaged better with the teaching methodology, which may affect the overall student perception. It is important to note that all questions in the survey faced the same way, with an agreement indicating a positive response towards flipped learning. This may have introduced acquiescence bias into this study. Equally, as the surveys were carried out in class there may also be an element of social desirability bias. However, even when taking these factors into consideration, there still appears to be a significant benefit to the flipped classroom approach in both performance and student satisfaction.

From a teaching perspective, this approach is heavily front-loaded time wise with creating the online resources, but this is regained in subsequent years, as only minor updates may be needed. The major benefit of this approach is the ability to engage with students, developing a stronger working relationship, identifying common areas of strength and weakness to allow tailoring of the taught sessions to the individual group. The increase in performance and general student satisfaction is a compelling argument to continue with and refine this pedagogical approach for teaching molar calculations.

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Table and Figure Legends

Table 1: Summary of student engagement and exercises by week

Table 2: Summary statistics of student performance pre- (2017/18) and post- (2018/19) flipped learning

Table 3: Usage statistics for calculation videos by week

Table 4: Summary of overall percentage responses to anonymous 5-point Likert scale questionnaire. Values indicate the overall percentage responses at each perceived level of the scale as a summary of all questions.

Figure 1: Mark distribution for students attempting the summative end of module online assessment, comparing students taught by peer-instruction only (red bars, n=51) and students taught using the flipped classroom methodology (biochemistry blue bars, n=45 and genetics green bars, n=44).

Figure 2: Divergent stacked bar chart centred around the mean neutral value indicating the percentage response rates to anonymous questionnaire. Red bars strongly disagree, yellow bars disagree (none shown), grey bars neutral, blue bars agree and green bars strongly agree.

Tables

Table 1

Weeks 1, 4 & 7	**Weeks 2, 5 & 8**	**Week 3, 6 & 9**	**Week 10**
Videos made available to students	Peer instructed homework question in class	Peer instructed formative example questions in class	Summative Assessment

Table 2

Year	**N**	**Mean**	**Std Deviation**	**Std. Error Mean**

2017/18	51	55.96	17.508	2.405
2018/19	89	63.09	18.571	1.958

Table 3

Week	Video length (mins)	Total views	Estimated total watched (mins)	Average views per student
1	21	340	7140	3.5
4	15	254	3810	2.6
7	23	281	6463	2.9

Table 4

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Overall percentage response	0.53	0	6.7	27.7	65.1

Figures

Figure 1

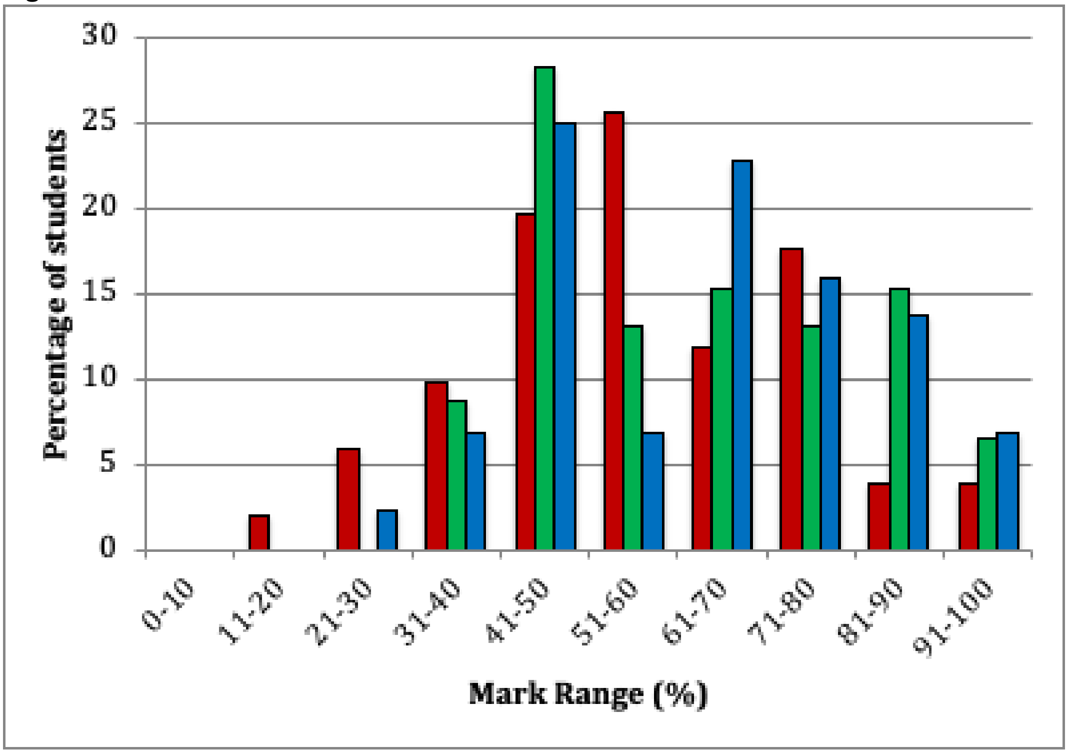
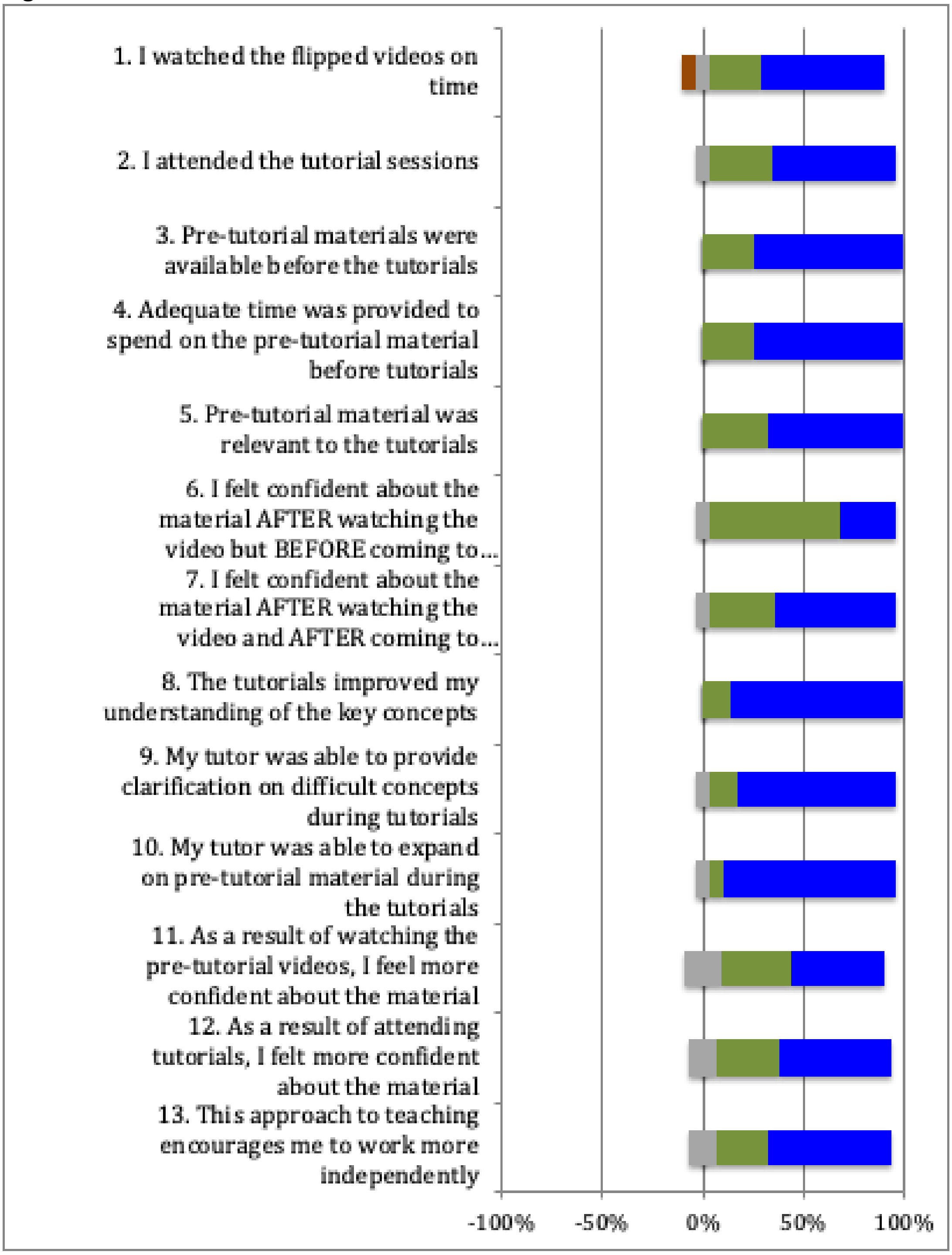


Figure 2


1. I watched the flipped videos on time
2. I attended the tutorial sessions
3. Pre-tutorial materials were available before the tutorials
4. Adequate time was provided to spend on the pre-tutorial material before tutorials
5. Pre-tutorial material was relevant to the tutorials
6. I felt confident about the material AFTER watching the video but BEFORE coming to...
7. I felt confident about the material AFTER watching the video and AFTER coming to...
8. The tutorials improved my understanding of the key concepts
9. My tutor was able to provide clarification on difficult concepts during tutorials
10. My tutor was able to expand on pre-tutorial material during the tutorials
11. As a result of watching the pre-tutorial videos, I feel more confident about the material
12. As a result of attending tutorials, I felt more confident about the material
13. This approach to teaching encourages me to work more independently
-100%
-50%
0%
50%
100%