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Abstract

Cambridge undergraduates have regular active-learning opportunities in small-group tutorials, in which they solve problems and discuss ideas based on course material. Would they see any value in performing similar tasks in flipped-classroom settings, or would they regard the introduction of a second active-learning modality as redundant? Following the replacement of traditional lectures with flipped teaching within three physiology courses, with tutorials ongoing, questionnaire responses showed that students felt that they learned and understood more, and felt better-prepared for exams. Although similarities were recognised, the context of the active learning evidently made flipped classroom and tutorial teaching feel very different, probably because of the different levels of attention from the instructors. Questionnaire and interview comments suggested a complementarity between the two approaches, in that engaging with problems within a flipped classroom could give students more confidence in tutorials and in essay-writing, while tutorials offered more opportunities for individually-tailored feedback.

Keywords

Active learning; course evaluation; curriculum; pedagogy; student learning

Cover Page Footnote

The authors would like to thank Darerca Owen and the Department of Biochemistry for the loan of their 'clickers'; Matthew Moss and Turning Technologies kindly granted a license for the use of the associated software. We thank the Department of Physiology, Development & Neuroscience for facilitating this study, and Andrew Murray for the use of his lecture material. Finally, we would like to thank the two anonymous reviewers of the earlier version of this manuscript, for their very insightful comments and suggestions for improvement, and all the students who gave their time to participate in our surveys and interviews.

Active Learning in Flipped Classroom and Tutorials: Complementary or Redundant?

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Cambridge undergraduates have regular active-learning opportunities in small-group tutorials, in which they solve problems and discuss ideas based on course material. Would they see any value in performing similar tasks in flipped-classroom settings, or would they regard the introduction of a second active-learning modality as redundant? Following the replacement of traditional lectures with flipped teaching within three physiology courses, with tutorials ongoing, questionnaire responses showed that students felt that they learned and understood more, and felt better-prepared for exams. Although similarities were recognised, the context of the active learning evidently made flipped classroom and tutorial teaching feel very different, probably because of the different levels of attention from the instructors. Questionnaire and interview comments suggested a complementarity between the two approaches, in that engaging with problems within a flipped classroom could give students more confidence in tutorials and in essay-writing, while tutorials offered more opportunities for individually-tailored feedback.

INTRODUCTION

Active learning within a small-group teaching setting forms an important part of the education offered by many universities worldwide, while flipped-classroom teaching (FCT), introduced more recently, is gaining popularity within the higher education sector. There is a growing body of work based around students' subjective perceptions of the flipped classroom experience in STEM subjects, compared to traditional lecturing (e.g., Ramnanan & Pound, 2017; Rotellar & Cain, 2016). For example, the preclinical medical students surveyed by Street et al. (2015) felt that flipped-classroom teaching had improved their understanding of the course material and provided better preparation for exams. The purpose of the present study was to examine whether undergraduates who had regular opportunities for active learning in small-group tutorials would also feel that FCT benefited their studies in this way, or whether the similar nature of the problem-solving exercises would leave them feeling that they would have learned more from a didactic session.

The Flipped Classroom Approach

"Flipped classroom" refers to the swapping of tasks typically engaged with during class, that is, the formalised teaching settings in an instructor's presence, and those carried out in independent study time (Akçayır & Akçayır, 2018). The rationale for the flipped approach is to augment the interactive and dialogic nature of students' engagement with the instructor, departing from the more traditional, one-way knowledge flow from teacher to student. This facilitates "discussion, solving problems proposed by the students, hands-on activities, and guidance" (Akçayır & Akçayır, 2018, p. 334). Learners must become familiar with the necessary content in advance, often utilising online material; when learners come to the classroom they can then be challenged to a greater extent, with increased emphasis on deep thinking and collaborative learning (McNally et al., 2017). Although often characterised primarily as an inversion of class-internal and class-external activities, changes to the tasks themselves contribute to enhancing the learning process (Murillo-Zamorano et al., 2019).

FCT's potential advantages have been widely discussed, including the emphasis on active learning, improvements in motivation and greater scope for tailoring teaching and learning to students' needs (Díaz & Narciso, 2019). The teacher can respond with immediate feedback to student answers, which might be communicated electronically, and can adapt the session accordingly. There have been many reports of improvements in students' learning outcomes following flipped courses (e.g., Bhagat et al., 2016; Mason et al., 2013), although the results from the study of Jensen et al. (2015) suggest that it might be the increase in active learning, rather than the flipped classroom approach *per se*, which results in these positive effects. O'Flaherty and Phillips (2015) indicate that an enduring impact on learning is difficult to prove, given the limited longitudinal data regarding the relationship between FCT and learning performance indicators (see also Bouwmeester et al., 2019).

FCT's potential benefits must be balanced against the additional preparation time likely required, both by students and teachers (Herreid & Schiller, 2013; Mok, 2014). Some students evidently do not feel confident in their mastery of more complex material, prepared independently in advance of the flipped sessions (Ramnanan & Pound, 2017), and students may feel isolated from the learning process when trying to assimilate content on their own (Rasheed et al., 2020). Within the flipped classroom, however, sub-groups of students can be formed within the wider cohort and encouraged to work together. There is some evidence to suggest that incorporating a collaborative element into FCT approaches can improve examination performance (Foldnes, 2016), critical thinking and collaborative practices (Gomez-Lanier, 2018). A recent systematic review of the literature on medical students' perceptions of the flipped classroom approach found that students particularly appreciate the increased opportunities for active learning and group work (Ramnanan & Pound, 2017), although some individual students can have negative perceptions of the value of peer learning (He et al., 2019).

LEARNING CONTEXT: SMALL-GROUP TEACHING IN CAMBRIDGE

As mentioned above, flipped-classroom teaching can involve an element of small-group learning, if students are placed in sub-groups for the purposes of discussing answers and solving problems together. Active learning in a collaborative setting also features in some forms of small-group teaching (SGT), although

SGT is a wider term defined only by the limited numbers of students involved, encompassing more didactic forms of teaching too (Exley & Dennick, 2004). The SGT in Cambridge which is relevant to the current discussion falls into the 'Tutor-led SGT' category of Exley & Dennick (2004), and within this would be best-described as a 'tutorial', as opposed to a 'seminar' or a 'problem-based learning' group. Indeed, these SGT sessions, which have been run for centuries within the universities of Cambridge and Oxford (Morgan, 2013), are referred to generically as 'Oxford tutorials' in the literature. We shall use this term throughout, although in Cambridge these SGT sessions are locally known as 'supervisions'.

While Exley and Dennick (2004) cite 4-12 as typical numbers of students in a tutorial group, there would usually be 2-4 students in a Cambridge science tutorial. They would be joined by an academic tutor, who would have particular expertise in the topic in question but might range in experience from a postgraduate student to a full professor. Each student in Cambridge is a member of one of around 30 colleges: the tutors are appointed by the separate colleges, not centrally. A tutor might teach the same students weekly for the full academic year or just for part of it, and has considerable autonomy in how their sessions run. Typically, students are encouraged to ask and answer questions about the course material presented previously in large-group lectures and practical classes. They are often set problems to consider and discuss as a group. The tutor might explain new ways to understand the material, lead a conversation about its implications, suggest wider reading, recommend approaches to preparing for summative exams, and set and mark work which would be discussed in the next session. Each tutorial session lasts for one hour, and there is one per week in each major module a student is taking.

The weekly tutorials are intended to complement the lectures and practicals which the students also receive. The lectures in the courses of interest here typically follow the traditional, didactic format and are often fact-heavy. While a student would likely have a different tutor to their peers from another college, all students attend the same lectures (three per week in each major module) and ultimately sit the same summative assessments. Tapper and Palfreyman (2002) suggest that the direction taken in lectures and tutorials is disparate if not completely unconnected, since academic faculties take central control of lectures, while tutorials are organised separately by the colleges. However, Horn (2013) sees a much closer relationship, with lectures essentially supporting Oxford tutorials in humanities subjects, and tutorials supporting the lecture courses in some science subjects. Morgan (2013) explains that while lectures do not necessarily prohibit dialogue or debate, the tutor offers personal guidance in the Oxford tutorial and this is where the student is challenged and held accountable for their learning, requiring them to take an "active rather than a passive role" (North Report of 1997, 163-64; cited in Morgan, 2013). Oxford tutorials are believed to place high-level academic demands on students, including the opportunity to develop critical thinking skills (Cosgrove, 2011), with a focus on students' autonomy in this regard (Beck, 2007).

Oxford tutorials might have different roles according to discipline (Horn, 2013; see also Beck, 2007). In Ashwin's studies (Ashwin, 2005, 2006), students and academics in the sciences seemed more likely than those from the humanities and social sciences to view tutorials as an opportunity for tutors to help students understand difficult concepts, as opposed to the more constructivist conception of "a place where new positions on the topic are developed and refined" (Ashwin, 2006, p. 656). The Oxford tutorial is evidently not a fixed and unified teaching method, and for early-years science students it might involve more didactic teaching than is commonly supposed, but it is always centred around students asking and answering questions.

COMPARING AND CONTRASTING THE FLIPPED CLASSROOM WITH TUTORIALS

This study examines the effects of introducing FCT, as a substitute for traditional lectures, into a course in which students already had regular active-learning opportunities in their tutorial sessions. In both FCT and tutorials, students are asked to assimilate material prior to the live session, and then in that session work through problems introduced by an academic instructor, often as part of a group, with immediate feedback. Both teaching methods have the potential for promoting interactivity and meaningful teacher-student and student-student dialogue, facilitating active and student-centred learning and moving away from a top-down mode of imparting knowledge (Morgan, 2013). There are three key differences, however, between FCT and the small-group teaching characterising Oxford tutorials:

1. The instructor-student interaction in the tutorial is much more intensive, owing to the very high instructor: student ratio (around 1:3). In FCT, one instructor would typically oversee a much larger number of students (over 350 in one of the courses considered here), and so there would be much less interaction between the instructor and any one individual, and therefore much less opportunity for a given student to ask questions and direct the discussion.
2. In tutorials, all students work together in the same group, guided by the tutor. Students may or may not be working in groups in FCT classes, but if they are encouraged to work collaboratively (as in our case), there would be multiple groups within the same classroom, working in parallel on a common problem.
3. Because tutors are recruited and managed independently by the colleges within the Oxford tutorial system, Horn (2013) reports tutors feeling quite free to develop their sessions as they see fit, not needing to coordinate with colleagues, nor necessarily plan what will be covered ahead of time. This sits notably at odds with FCT, which is generally part of a centrally-run course with learning objectives specified in advance.

Anecdotally, several experienced academic colleagues had told us that they did not feel that FCT would add anything of value to our physiology courses, given that our students already had regular opportunities for active learning within their weekly tutorials. For them, the similarities in teaching methods outweighed the differences, but would students see things the same way? We addressed this by asking students to comment in questionnaires on how replacing traditional lectures with FCT classes affected their learning, understanding and preparation for exams; their weekly tutorials continued throughout. We pursued the similarities and differences between their experiences of FCT and tutorials in interviews. The results of this study were of interest to us

in considering future course design, and will be of wider interest to academics at other institutions, who may be contemplating introducing a second form of active learning into their teaching.

METHODOLOGY

Flipped classroom teaching was introduced, as a substitute for regular, traditional lectures, into three physiology modules. The students' experiences of this were assessed through questionnaires and interviews. Three cohorts of undergraduates participated in this study:

1. 187 First-year Natural Science students taking a module called NST 1A Physiology of Organisms (henceforth PoO). The flipped classroom course within this module was given in November 2018.
2. 39 Second-year Natural Science students taking NST 1B Physiology (henceforth Phys). The flipped classroom course was given in February and March 2020. All of these students had taken the PoO module in the previous academic year, which had included the 'flipped' course outlined above.
3. First-year medical and veterinary students (n = 319 and 67 respectively) taking M&VST 1A Homeostasis (henceforth HOM). The flipped classroom course was also given in February and March 2020.

It was briefly explained in advance to all three cohorts, via a page on the virtual learning environment (VLE), that 'flipped classroom' teaching involves core material presented in advance, while the class itself becomes interactive. This was backed up by a YouTube video of Eric Mazur explaining his own experiences of teaching in this way, together with a link to a supporting paper (Mazur, 2009). Students were told that their reaction to the flipped teaching would form part of an educational study. They were provided with course material in advance of the live classes (see Table 1), and were told to work through it since they would need to be familiar with the material in order to be able to participate in those classes. They were told that they would have the opportunity to ask questions after each class, if anything was unclear. Whether or not the students had prepared the course material in advance of the live classes was assessed only through self-declaration in the questionnaire issued at the end of the courses: preparatory work was not tracked or graded. Within the live sessions themselves, which took place in traditional, tiered lecture theatres, students were asked to self-organise into small groups (Table 1). Members of each group were asked to work together to discuss and answer the questions posed by the single academic instructor present.

Weekly tutorials, organised and overseen by the separate colleges, had been given throughout the academic year in support of the lectures, and continued throughout the weeks that these three flipped courses were taking place. Students should each have had one tutorial based on the flipped PoO course, or two if taking the longer Phys and HOM courses. Many different tutors were involved in running these sessions. They had been made aware of the new, flipped, format of the courses, but had not been told to adapt their tutorials in any way.

The academic instructor leading these three flipped courses (MJM) also had a tutorial role in one of the colleges. Many of the questions used in the flipped courses, including the essay question discussed in the PoO course, were based on those previously used by MJM in his own tutorial sessions.

The 2018 PoO Module

A three-lecture course on 'Nutrient Acquisition' within the PoO module was converted to a flipped classroom format when the first author took over as a sabbatical replacement. The academic content was changed only slightly, to suit the rest of the 2018-2019 module, and was made available as PowerPoint presentations and lecture notes, uploaded in advance to the VLE. No video presentations were included, and no extra time was freed up in the course for preparation (Table 1).

In the live classes, students were asked to self-organise into groups of 4-6. These sessions, each one hour long, consisted largely of the instructor asking the members of each group to work together to come up with answers to a series of questions and discuss ideas, based on the material they had read in advance. Some of the questions were multiple-choice questions (MCQs), answered with the use of 'clickers' (Turning Technologies ResponseCard RF). One clicker was given to each group, and the students were told by the instructor how to use the clicker within the class itself. After students had been given a few minutes to collaborate on the answers to each MCQ, anonymised clicker responses were revealed to the audience together with the correct answers. Answers were collected and presented using Microsoft PowerPoint 2016 running in association with TurningPoint software (Turning Technologies). The students were also asked other types of questions including calculations, diagram completion and open-ended questions, which did not involve clickers and required oral responses. In all cases, the correct answers to the questions were explained and often expanded on afterwards, and the instructor would answer any follow-up questions from the audience.

In the last live class, students were invited to consider how they might structure an essay on the topic. The essay title was representative of a type of essay that the students could expect in the end-of-year exam. Having discussed in their groups what elements they might include in the introduction, different strands of the essay's argument and its conclusion, the instructor compared the answers that the students shared with the instructor's own approach. This exercise was intended to help them with two of the course learning outcomes, which were to be able to

Table 1. **Major Differences in the FCT Courses Given to the Three Cohorts of Students**

Module	Material provided in advance of class	Course time freed up for preparation?	Student subgroup size in class	Student responses in class	Active learning tasks
PoO	Lecture notes plus PowerPoint presentations	No	4-6	Clickers and oral	Multiple-choice questions Open-ended questions Calculations Diagram completion Essay structuring
Phys	Lecture notes plus videos	Yes	2-3	Oral only	Open-ended questions Diagram completion
HOM	Lecture notes plus videos	Yes	3-4	Oral only	Open-ended questions Diagram completion

integrate related topics from separate parts of the course, and to be able to develop cogent and critical arguments based on the course material.

At the end of the last live session, the students were each given a paper questionnaire (see subsection entitled "The questionnaires", below). All students were also invited to volunteer to be interviewed by the second author, whom they had not previously met, in order to explore their feelings about the FCT approach in more detail. It was explained in the e-mail asking for volunteers that the first author (their instructor) would not be present at the interviews and would not be told which students had volunteered. From the cohort, 12 students volunteered to be interviewed, 3 in person and 9 by telephone. Despite the convenience-sampling approach taken, the 12 interviewees varied in their linguistic and cultural background, gender, and types of school attended before university. All interviews were audio-recorded and conducted within 11 weeks of the classes; the mean interview length was 18 minutes. Despite the delays between the course and interviews, which were necessitated in some cases by the vacation period which followed soon after the course ended, students appeared to have no difficulties in recalling details of the flipped classroom courses. NVivo software was used to carry out thematic analysis of the qualitative data from interviews and all three sets of course questionnaires (PoO, Phys and HOM), to capture students' views holistically, both favourable and unfavourable (Comber & Brady-Van den Bos, 2018). All interviews were fully transcribed, salient points from each interview transcript in turn were coded, and core themes established on this basis.

The 2020 Phys and HOM Modules

Following the perceived success of the PoO course, it was decided to run the Phys and HOM courses on 'Digestive Physiology', usually given by the first author in a traditional lecture format, as FCT in the following academic year. Unlike the shorter PoO course which had been little modified, these courses were substantially adapted. The material was identical, but the Phys and HOM courses were presented separately.

Given that some of the PoO cohort in the previous year had complained about the amount of background preparatory work, three of the six timetabled lecture class-times (1 hour each) were redesignated as preparation time for students, and no classes were scheduled in those hours. The 'core' content of the established six-lecture series was made into online video presentations, and the students were encouraged to watch these in the time that had been freed up in the timetable for this purpose. Videos were not used in any other lecture courses in PoO, Phys or HOM. The videos in total lasted 42 minutes longer than the three hours freed up, because the core content from six lectures had been compressed down to three units.

In the three "flipped" classes, the students were asked to form small groups (2-3 students for Phys, 3-4 students for the larger HOM module). No clickers were used in these courses, in part because we wanted to move away from MCQs and towards more synthetic and open-ended questions which would allow us to explore deeper levels of understanding, and in part because the limited numbers of these devices available to us would not have permitted sufficiently small student subgroups to be formed in the large HOM classes. Instead, students were invited to shout out answers, once they had had a chance to discuss the questions within their groups. Open-ended and diagram-completion questions were similar to those used in the PoO course, but there were neither calculations nor detailed discussions of essay structure. Much of the 'peripheral' content of the established lecture series which had not been included in the videos was introduced, in the context of questions or their explanations, in the flipped sessions.

The questionnaire given to Phys and HOM students in the last of their flipped classes was almost identical to the PoO questionnaire. The 2020 courses ended at the point that the coronavirus pandemic hit the UK: no follow-up interviews could be conducted, and a comparison of examination marks which had been planned could not proceed.

The Questionnaires

Paper questionnaires were used in this study because of the very low response-rate that the department had seen from online questionnaires in the past. Questionnaires were given out in the last classes of each flipped course and were also available afterwards, including as electronic copies on the VLE. Only a handful of students submitted questionnaires after the last classes, however.

The questions asked students to compare the flipped courses with the traditional lecture courses they had replaced, the style of which they were very familiar with. Careful consideration was given to whether students should also be directly asked to compare the flipped classes with tutorials, within the same questionnaires. Rather than this direct comparison, the main purpose of our study was to establish whether replacing lectures with FCT would benefit a course which already offered active learning opportunities in this other context. In line with recommendations in the research methods literature (e.g., Arksey & Knight, 1999; Cohen et al., 2017), it was decided that it would be better to avoid leading questions of this nature, because this would inevitably introduce the notion that there are similarities between the two ways of teaching and, following this, make it hard to untangle casual observations from deeply-felt concerns. We reasoned that if the students felt that the flipped-classroom courses were simply repeating the same active learning experience that they were getting in their ongoing tutorials, this would be clear from negative responses, expanded upon in the open-ended comments. If students did not spontaneously recognise similarities, or did not regard them as significant enough to mention, we could reasonably conclude that any cross-over in learning method did not reflect a problematic redundancy.

The questionnaires contained five Likert-scale questions:

1. "Did you read through the online material (lecture notes and slides)..." (PoO), or "Did you watch the videos..." (Phys/HOM), "...associated with each topic in advance of the live presentations?".
2. "How much do you feel you learned from the flipped classroom approach taken in Nutrient Acquisition (this includes both prior reading and the presentation itself)..." (PoO), or "How much do you feel you learned from the flipped classroom approach taken in Digestive Physiology (this includes both the videos and the presentations)..." (Phys/HOM), "...in comparison to what you would have learned from traditional lectures?"
3. "How would you rate the depth of your understanding gained from the flipped-classroom approach, in comparison to that gained from traditional lectures?

4. "To what extent do you feel that the flipped classroom presentations helped prepare you for tests and exams, in comparison with the traditional lecture format?"
5. "Over a whole, year-long lecture course, what proportion of lectures would you recommend should be presented as "flipped-classroom" presentations, in the future?"

For Question 1, the three answer options were that the student in question had either (A) not looked at the available material, (B) had looked at some but not all, or (C) had looked at all of it. For Questions 2-4, the five answer options available ranged from (A) "much less", (B) "a little less", (C) "about the same", (D) "a little more" and (E) "much more". For Question 5, the answer options were (A) "None", (B) "A small proportion", (C) "Half", (D) "The majority" and (E) "All". Open-ended comments boxes followed each question, and an "Any other comments?" box concluded the questionnaire. Some further questions followed in the PoO questionnaire, relating to another study: these are not considered here.

The Likert-scale answers were converted into numerical scores for purposes of averaging (scores from 1 to 3 for Question 1, scores from 1 to 5 for Questions 2 to 5). Where a student had ringed more than one answer, an average value was used. Mean scores for each of the three cohorts (PoO, Phys and HOM) were compared using one-way analysis of variance (ANOVA; see Norman (2010) for a defence of this approach). Although there were differences between how the PoO course and the Phys/HOM courses were presented, in particular concerning the use of clickers and video presentations (Table 1), it was not the purpose of the present study to compare flipped course designs in any detail. For this reason, it was decided not to alter the questions asked of the three cohorts of students in any substantial way.

Ethical Approval

This project was approved in advance by the Faculty of Biology, the Head of Teaching in the department concerned, and the Course Organisers. Consent was obtained from the relevant colleague for the adaptation of their lecture material for the PoO course. Ethical approval was obtained from the institutional Ethics Committee. It was made clear to students that their comments would remain anonymous, and that participation was voluntary.

RESULTS

Out of 187 PoO students, 123 (66%) completed questionnaires. Of the 39 Phys students, 29 (74%) completed questionnaires. Of the 386 HOM students, 113 (29%) completed questionnaires. Some of the Phys students may have answered a similar questionnaire based on their PoO course in the previous year, but because the surveys were anonymous this could not be established for certain. The HOM students did not take PoO or Phys, so this was a totally separate cohort.

Question 1 asked students about the amount of preparation they undertook before attending the flipped classes. This preparatory work was not tracked or graded: it was entirely up to the students how much time to put into it. As shown in Fig. 1, the majority of the Phys and HOM students responded with option C, indicating that they had looked at all the available material. Relatively more students in the PoO cohort, who had not had any time in their schedules freed up for preparation, responded with option B, that they had looked at some but not all of it. The extra time needed for advance preparation represented a common concern among all three cohorts. Some students commented that watching video recordings took longer than the videos themselves, because they would periodically stop the recordings to make notes.

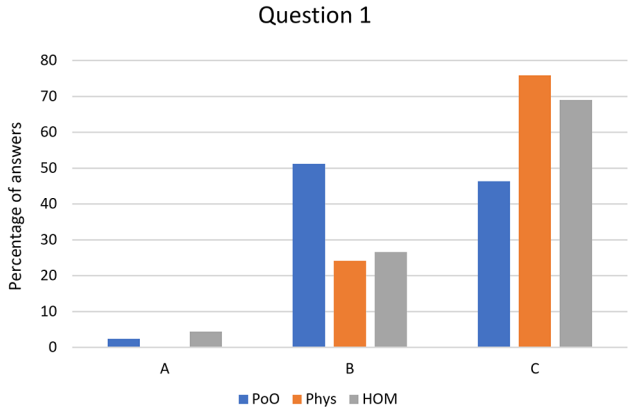

Figure 1. Responses of the three cohorts to Question 1, relating to the amount of preparation done for the flipped sessions (A, had not looked at the available material in advance; B, had looked at some but not all; C, had looked at all of it).

Question 2 asked students how much they felt they learned from the flipped classroom approach, while Question 3 asked how they would rate the depth of understanding they had gained, in both cases compared to the traditional lecture format which the students were familiar with. Although Questions 2 and 3 were similar, Question 2 was targeted towards factual knowledge, while Question 3 was intended to assess the conceptual framework which brings these facts together (e.g., Krathwohl, 2002). This distinction is particularly important for undergraduate science courses, which are often fact-heavy. In retrospect, we felt it possible that the two questions might be conflated by the students taking the survey, and so the answers to the two questions are considered together here. In both cases and for all three cohorts, the most frequent response was D, "a little more" (Fig. 2, 3).

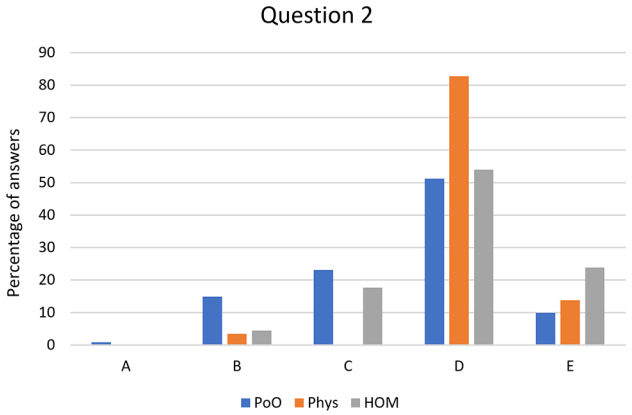

Figure 2. Responses of the three cohorts to Question 2, relating to how much the students felt they learned from the flipped-classroom courses, compared to traditional lectures (A, much less; B, a little less; C, about the same; D, a little more; E, much more).

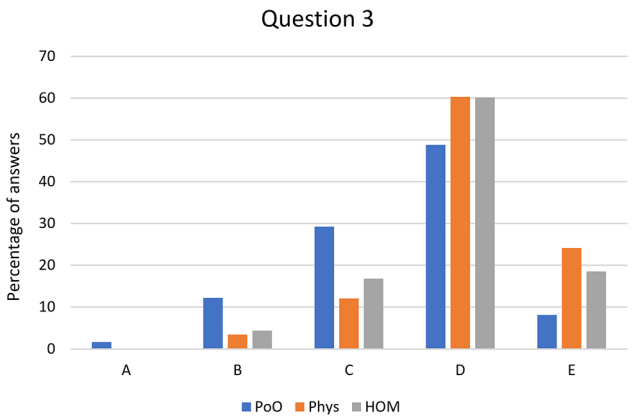

Figure 3. Responses of the three cohorts to Question 3, relating to how the students rated the depth of their understanding gained from the flipped-classroom courses, compared to traditional lectures (A, much less; B, a little less; C, about the same; D, a little more; E, much more)..

The written comments gave some of the reasons why the students felt that their understanding had been enhanced through the flipped classroom:

> It was easier to understand the core content as you could pause/go back on the videos and the 'extra material' could be discussed in greater depth during the lectures (*Phys questionnaire*)

This comment forms an interesting counterpoint to the common complaint about the time spent watching preparatory videos. Many students reported that learning was facilitated during the flipped classes as the greater level of engagement required meant that it was not possible to switch off. The flipped classroom approach also helped students reflect on the material in a different way:

> what the flipped classroom teaching actually makes possible for us is to apply the concepts […] and also […] if you make a mistake during the flipped classroom teaching then it makes it for you much easier to understand the concept and actually remember it because then you remember the mistakes you've made and you understand why it was wrong and this is not something that you could experience in regular lectures (*Interviewee 9*)

> This is big benefit of this style. Encourages thinking about consequences and what ifs…? (*Phys questionnaire*)

> Actually made me think about the stuff I had learnt rather than assuming I understood it. […] Felt like I was building on top of knowledge rather than trying to learn everything at once. (*HOM questionnaire*)

Some of the more measured comments suggest why option E ("much more" learning and understanding) was not so commonly selected in Questions 2 and 3. Any improvements in knowledge clarification, recall or understanding might be a result of any additional time taken in preparation, rather than the flipped classroom model itself.

> If this [*extra*] work was put in alongside traditional lectures maybe the same outcome? (*Phys questionnaire*)

> Depth of understanding currently is less - as could not complete videos. However, if had time would be better depth. (*HOM questionnaire*)

There was also a sense that when a group dynamic worked well, then group work was a positive aspect of the flipped classroom, but that the converse also held true. The following comment refers to the discussion encouraged between students within the flipped class:

> discussion makes us think deeper about the content of the videos - however relies on the people you are discussing with the make the [*sic*] discussion sessions helpful (*HOM questionnaire*)

How much work a student puts into the preparation for a flipped class will clearly affect their ability to participate constructively within the group: the fundamental role played by students' accountability for their learning as part of a flipped classroom approach has been widely recognised in previous research (e.g., Ramnanan & Pound, 2017; Rotellar & Cain, 2016).

The end-of-year summative assessments in these courses include multiple-choice and essay components. In rating their level of preparedness for these examinations following FCT as compared to traditional lectures, the great majority of students selected option C, "about the same", or D, "a little more" (Fig. 4). Positive perspectives included the following:

> because multiple choice forms such a large part of the exam […] having that just sort of reintroduced particularly at that point because it was so close to the end of the year, um and close to mocks and stuff, it was definitely helpful (*Interviewee 3*)

> I feel ready to start [*exam*] revision from a basis of good notes & understanding, many other series I need to go over my understanding & better improve my notes before I can even start revision. (*HOM questionnaire*)

> I found essay writing much easier, mostly regarding structure and the main points to be focussing on, as usually this is completely missed in all the details in normal lectures. (*Phys questionnaire*)

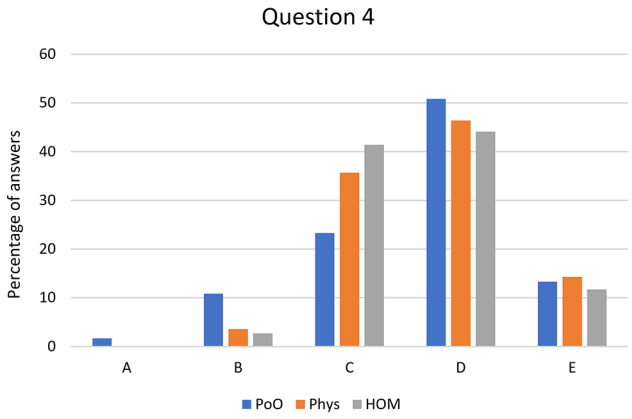

Figure 4. Responses of the three cohorts to Question 4. relating to how well-prepared the students felt for tests and exams following the flipped-classroom courses, compared to traditional lectures (A, much less; B, a little less; C, about the same; D, a little more; E, much more).

> Thinking around the subjects probably will have helped in essays, in trying to think laterally and draw connections. I think this will have helped. (*HOM questionnaire*)

Formative essays are set by tutors throughout the year and are often discussed in the weekly tutorials. The last two comments above suggest that the FCT approach usefully complements this aspect of tutorial work. However, not all students were certain that the more in-depth learning gained would be beneficial for the summative assessments at the end of the academic year:

> difficult to balance broad themes with detail in exam essay in time given so not sure how much broader thinking can be incorporated into timed essays. (*Phys questionnaire*)

This comment suggests that the deeper understanding of underlying physiological concepts which was promoted in the flipped sessions might not be something that this student could take advantage of in the summative assessments, given the time limitations. One of the learning outcomes of the Phys course as a whole was that students should understand how different organ systems interact to yield integrated physiological responses, and this does require an understanding of such concepts. If producing a timed essay of this nature were impossible, this would suggest a failure in alignment between course objectives and the examination process, but there was no indication that this was a widespread view among the student cohort. It would, however, appear that some students would benefit from further guidance in how to translate the broader perspective gained from the flipped classroom into specific exam technique – guidance which would typically come from their tutors.

Finally, students were asked what proportion of lectures should be flipped in future. For the PoO and Phys cohorts, the most common response was B, "a small proportion"; slightly more HOM students responded C, "half" (Fig. 5). Several factors were cited to support these views, the nature of the academic content being most commonly raised. Despite broad consensus that only certain topics would suit flipped classroom delivery, there was no agreement on which topics they would be. Some felt FCT was the more suitable way to teach physiological topics that required much factual knowledge, while traditional lectures might be better for others:

> [*FCT*], for me, is a more sensible way to cover factually-dense subjects. Lecs [*lectures*] better for conceptual understanding. (*HOM questionnaire*)

> I think it really depends on the topic. Digestion worked well as the content is quite factual, so bringing this together in the flipped classroom was useful, however other topics may be less suited for this style. (*Phys questionnaire*)

Others took the opposite view, however:

> Dependent on topic. for less factual learning, this is wonderful. For more factual stuff, lectures suffice. (*HOM questionnaire*)

> maybe for the more conceptually difficult content (*Phys questionnaire*)

Students also raised concerns about the required preparation time, the feeling that the benefits of FCT would depend on the lecturer, and the quality of background material provided. Overall, there was a clear sense that FCT should not replace traditional lectures entirely, but there were elements (especially the preparatory videos) that should be ubiquitous.

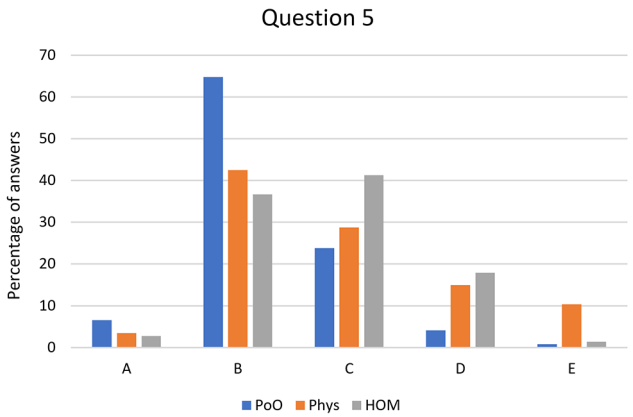

Figure 5. Responses of the three cohorts to Question 5, relating to what proportion of the teaching over the course of the year should be flipped-classroom, as opposed to traditional lectures (A, none; B, a small proportion; C, half; D, the majority; E, all).

Comparing Between Cohorts

Although it was not the main focus of this study, it was necessary to see if there were any substantial differences in how the three cohorts of students answered the questionnaire questions, before drawing general conclusions. The Likert-scale answers having been converted to numbers (1 to 3 for Question 1, 1 to 5 for the other questions), one-way ANOVA tests were performed on the data for each question in turn. These showed statistically significant differences ($p<0.01$) between the means of the three student cohorts for all questions other than Question 4 ($p=0.895$). In all cases, the mean for the PoO cohort was lower than the means for the Phys and HOM cohorts, although the difference was never large in absolute terms (Table 2). We suggest why this might be in the Discussion section. Importantly, the mean scores for all cohorts were well above neutrality (i.e. answer C, numerical value 3) for questions 2, 3 and 4, indicating that all three cohorts felt that the FCT benefited their learning, in comparison with traditional lectures.

Table 2. **Mean ± standard deviation for each cohort of students**

Question	PoO	Phys	HOM
1	2.44 ± 0.55, *n*=123	2.76 ± 0.44, *n*=29	2.65 ± 0.57, *n*=113
2	3.55 ± 0.89, *n*=121	4.07 ± 0.53, *n*=29	3.97 ± 0.77, *n*=113
3	3.50 ± 0.87, *n*=123	4.05 ± 0.71, *n*=29	3.93 ± 0.73, *n*=113
4	3.63 ± 0.91, *n*=120	3.71 ± 0.76, *n*=28	3.65 ± 0.72, *n*=111
5	2.28 ± 0.68, *n*=122	2.86 ± 1.06, *n*=29	2.78 ± 0.81, *n*=109

Comparing Flipped Classroom and Tutorials

We wanted to see whether students would regard any cross-over between FCT and tutorials, the students' weekly, small-group teaching sessions known locally as 'supervisions', to be significant enough to raise as an issue without prompting. Our questionnaires therefore avoided asking about this directly. In fact, from the 265 completed questionnaires, only 13 students mentioned tutorials at all (4 PoO, 2 Phys and 7 HOM) in their open-ended

Table 3. **Open-ended questionnaire comments mentioning tutorials ('supervisions' or 'supos')**

Comment number	Comment	Question this elaborates on, & selected option	Cohort
1	too many flipped classroom sessions might take too long to prepare for and reduce the time I can spend on supervision work and other reading	5; B	PoO
2	since the format is to [*sic*] dependent on preparation if other things e.g. supervision work need to be prioritised, it would be easy to fall behind	5; B	PoO
3	They work well, but previous preparation for a lot of the course, alongside supervision work, could become unmanageable	5; B	PoO
4	Very analogous to supervisions so to do lots would not be useful – however a few are nice – effectively like getting perspective of a different supervisor	5; B	PoO
5	it felt like the lecture was almost a supervision, so details were explored more thoroughly	2; D	Phys
6	[*I feel somewhat less prepared for tests/exams*] because less on core content (although haven't had supervisions yet)	4; B	Phys
7	Felt the live sessions were similar to a large supervision which I appreciated	2; D	HOM
8	Although college supervisions tend to make up for any lack of understanding	3; D	HOM
9	More supos/practicals on digestion would be useful!	4; C	HOM
10	The information is still the same and reinforced by supervisions	4; C	HOM
11	Still doesn't beat asking supervisors, and working small groups	3; D	HOM
12	most exam aid is from supos	4; C	HOM
13	questions in 'lectures' were supervision style - so stretched the concepts. took longer however.	2; D	HOM

comments (Table 3). Three only mentioned tutorials in passing as another source of work (1, 2, 3), four of them note that tutorials and FCT are similar – although evidently not identical – but this was not seen as a problem (4, 5, 7, 13), while another five refer to the continued importance of tutorials which are regarded as complementary (6, 8, 9, 10, 12). Comment 11 compares FCT unfavourably with tutorials, seemingly on the grounds of group size.

The crossover between FCT and tutorials was actively pursued in the interviews following the PoO course. Students clearly recognised similarities in terms of the interactive nature of both types of teaching. The differences they highlighted generally related to the small tutorial group-sizes, which allowed for increased individual attention from their academic tutors ('supervisors'):

> I was going to say it resembled a supervision in the sense that it was more of us contributing than us absorbing information. I can't say it's entirely similar because we we can only answer through the clicker, we can't give our answers in prose, we could write it down but it wouldn't be evaluated by the lecturer so it's different in that sense (*Interviewee 6*)

> in supervisions you are usually only together with one or two students or in a group of 3 or something like that, so it's much more individual I would say, and […] in supervision there is not the competitive aspect, while the flipped classroom teaching […] was actually more fun and people got more engaged because they wanted to get the marks and compare the results to others, so that's all so stimulating, I would say so there are similarities there are differences as well (*Interviewee 9*)

> I think the supervisions are definitely a more intense environment because you are directly confronted, you have a conversation and you need to answer something, and I think in the flipped classroom there are also definitely people who just didn't take part […] but I mean in the style of questions I think was kind of similar (*Interviewee 12*)

> I think yes [*the flipped classroom is similar to supervisions*] it is because in my supervisions, my supervisor also asks questions and then sort of asks has us answer and then he gave us explanations, well it's almost identical I think just with many more people (*Interviewee 4*)

As with the questionnaire responses, the similarities identified between FCT and tutorials were apparently not regarded as problematic. Attending the flipped classes might actually improve engagement within tutorials, compared with the normal approach of assimilating the course material through a traditional lecture:

> I already was very confident with the material before going into the supervision because I had to go through it myself […] so it wasn't so ok so let's sit here and try and understand this concept, [*but*] now apply this to more complicated problems (*Interviewee 3*)

Participating students had different academic tutors, who inevitably led their tutorial sessions differently (see Table 3, comment 4). This might account for some finding the two approaches more dissimilar than others:

> ...my supervisor doesn't typically like ask us a bunch of questions on the lecture notes, um he more gives us an opportunity to ask our own questions and then we walk through the lecture notes and that was very different to what we did in the flipped classroom (*Interviewee 8*)

In summary, the evidence from questionnaires and interviews suggested that although students recognised the similarities in the active learning opportunities provided in FCT and tutorials, the students' experiences of the two teaching methods were different. This seemed to relate largely to the more intense environment and personal attention possible in a tutorial, and could be exaggerated by different approaches to the course material taken by different academic tutors.

DISCUSSION

This study has shown that our undergraduates generally reported benefitting from FCT in the amount they felt they learned, their depth of understanding and how well-prepared they felt for exams, in comparison with the 'traditional' lectures they were used to. Both the traditional lectures and the flipped courses considered here were supported by weekly small-group teaching sessions (tutorials), organised by the students' colleges. Although tutorials differed by college, students would normally be made to perform tasks similar to those in the 'flipped classroom' sessions - indeed, many of the questions asked in the flipped sessions considered here were adapted by the first author from his own tutorials. Before the flipped courses were introduced, academic colleagues had expressed scepticism about what FCT could offer beyond this, and hence whether there would be any point in replacing traditional lectures with flipped classes. However, perhaps our most striking finding was how very few students spontaneously remarked upon this supposed similarity between FCT and tutorials, although they did recognise the cross-over when prompted to reflect on it in interviews. Despite the regular tutorials that students were still attending throughout the study, there was clearly no widespread feeling that flipped teaching was superfluous, and no indication that traditional lectures would under these circumstances have done a better job in enhancing the students' understanding. Indeed, several comments from questionnaires and interviews suggested that FCT and tutorials were complementary, in that the FCT approach could give students more confidence in tutorials and help them with the formative essay assignments set by tutors, while the greater opportunity to ask questions in tutorials helped to clarify any areas of confusion after the FCT classes.

These results must be interpreted with caution, however. The great majority of questionnaire responses came from students who were present in the final class of each series: we have little insight from students who failed to attend. The relatively low response rate from HOM students can be attributed in part to many having missed the final class. These students had an exam based on another course the following day, and some may have remained at home given escalating concerns about coronavirus. Factors contributing to positive responses to FCT among those students who did attend potentially include the 'novelty effect' of a different approach (Lo & Hwang, 2018), while feedback scores for teaching are also notoriously dependent upon the instructor (Shevlin et al., 2000). The introduction of video presentations doubtless contributed to student satisfaction in the Phys and HOM courses (see e.g., Ramnanan & Pound, 2017), but cannot account for positive scores in the PoO course which lacked them. Having the opportunity to pause and review videos meant that it took much longer for some students to get through the background material. This is not necessarily a bad thing, given that increased time taken in studying could in itself improve learning, but student comments suggested that adequate preparation might not be sustainable if FCT were implemented more widely. Complaints about increased workload have followed the introduction of flipped teaching into physiology courses elsewhere (Rae & O'Malley, 2017), but this has not universally been the case (Street et al., 2015). Some recent research suggests that overall working time may be re-distributed under the flipped classroom model (Bouwmeester et al., 2019; He et al., 2019). The medical students in the study of Bouwmeester et al. (2019) indicated that they did not need to spend as much time on revision prior to examinations.

Although they seemed to value the 'flipped classroom' courses, few students felt that FCT should account for more than half the teaching within the module. This was not because of any cross-over with tutorial work, but was apparently based largely on the work-load required to prepare for FCT classes, and also because of a perception that FCT would work better for some subjects than others. Mok (2014) proposed that FCT involving pre-prepared videos can be particularly useful in fact-heavy subjects, but our students were divided on whether FCT would be better for learning facts or concepts. Roehl, Reddy, and Shannon (2013) emphasized the usefulness of FCT in courses where information assimilated in advance can be applied to problem-solving or practical tasks in the flipped sessions. The practical application of content was most obvious in our HOM course, in which some of the questions asked of our preclinical medical and veterinary students in the flipped sessions related to how patients might be affected by different digestive conditions.

While we remain uncertain of the explanation for the PoO cohort responding with slightly less favourable average scores than the Phys and HOM cohorts, two factors likely contributed. One was the introduction of video material into the Phys and HOM courses, mentioned above. Secondly, PoO students were asked to prepare for the flipped classes in their own time, while the Phys and HOM students had timetabled lecture sessions reallocated for this purpose. The lack of 'clickers' in Phys and HOM evidently did not detract from the students' overall positive impression of these flipped courses.

CONCLUSIONS

From the positive student responses to all three FCT courses introduced, the lack of evidence that the students found interactive classes too similar to their tutorials, and student comments suggesting complementarity of the two approaches, we conclude that FCT can successfully coexist alongside small-group teaching sessions. Although the style of active learning may be similar when a FCT class is divided into smaller subgroups, and the tasks given to those subgroups are akin to those given to a tutorial group, we believe that the different levels of individual attention from the instructor represents the key distinction between these teaching types. The amount of individual attention will inevitably depend upon factors including group-size and physical setting: working in a relatively anonymous way in a large lecture theatre, as part of one group among many, evidently feels very different to tackling similar problems when sat at a table opposite an academic tutor. The intense learning environment in Oxford tutorials is likely to exaggerate the perceived difference between interactive small-group teaching and FCT, in comparison with other educational institutions which might offer small-group teaching with more students in a group. However, as long as those students know that their contribution is being individually monitored, we suggest that they would still regard FCT as offering a different type of learning experience. Although we were not able to investigate learning outcomes in the present study, increasing the amount of active learning would be regarded as beneficial by most teaching professionals, and active learning is popular among students too. The results of our study show that both FCT and small-group tutorials can usefully contribute to this, within the same course. These findings should be broadly applicable to other institutions considering introducing flipped classroom to courses with active

learning opportunities already available through small-group teaching, or vice versa.

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