Designing and Reflecting on Active Learning and Flipped Classrooms for Renal Physiology

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In this paper, we outline a case study describing the incorporation of active learning and flipped classroom techniques in a renal physiology module in 1st year medical school. The module was redesigned over a 2-year period within the teaching for understanding (TfU) framework (generative topics, understanding goals, performances of understanding and ongoing assessment) to include more active learning exercises (clicker response systems centered on clinically relevant problem sets and classroom assessment techniques – CATs), which culminated in flipping the classroom entirely during the 2nd year. The goal, was to evaluate student perceptions of the flipped classroom model and to reflect on the use of active learning generally. In the 1st year, clicker response systems were favorably received by students, however the anonymous nature of the clicker configuration meant it was not possible to track progress of individual students. CATs revealed that content areas without active learning exercises were often deemed the most unclear by students. Student feedback indicated that the flipped classroom model in the 2nd year was positively received, with students noting it encouraged them to attend classes more regularly and they believed it assisted in developing collaborative learning and knowledge application.

INTRODUCTION

In this paper, we describe the redesign of a renal physiology module in the first year of medical school at the University of Nevada, Reno School of Medicine, U.S.A., over a 2-year period from 2018-2019. This module was taught for the first time by the author in Fall Semester 2018 and again in Fall 2019. The module was a self-contained series of classes that focused on renal physiology and function, which took place within the second block (Block 2) of physiology modules for 1st-year medical students at the University of Nevada, Reno School of Medicine. Block 2 also covered cardiovascular and respiratory physiology, with other body systems being covered in other class blocks during the initial 18 months of medical school. In both years, the renal physiology module consisted of the following classes:

1. Overall review of renal function. (2 hours)
2. Control of glomerular filtration. (1 hour)
3. Body fluid compartments. (1 hour)
4. Dilution and concentration of urine. (1 hour)
5. Volume homeostasis and Na^+ / K^+ regulation. (1 hour)
6. Renal review / problem set class. (1 hour)
7. Renal handling of acid and base. (2 hours)
8. Renal acidosis disorders. (1 hour)
9. Renal team-based learning (TBL) class. (3 hours)

In both 2018 and 2019, there were 70 students enrolled in the module, with attendance not being mandatory, as is the case for all classes taught by non-clinical faculty at the University of Nevada, Reno School of Medicine. In previous years, these classes were taught almost exclusively with the lecture format, except for a TBL class. This near exclusive reliance on lectures and its inevitable drawbacks as a sole pedagogical approach (8, 47), led to speculation that active learning and student engagement were not sufficiently emphasized. This is potentially problematic as renal physiology is an area of medical science which students often find challenging (70) but this can be alleviated by active teaching and learning (19, 20, 39, 69). Upon taking up teaching of this module for the 1st time in 2018, the author sought to redesign the teaching of the module to include more active learning exercises, which ultimately led to flipping the entire module in the 2nd year of teaching. This paper presents student perceptions on these interventions as well as reflections from the author on how elements of the module were redesigned and worked in practice.

METHODS

Module design and redesign (CATs and clicker systems)

In this paper, we outline the design, teaching and redesign of a renal physiology module over 2 years (2018-2019). In the initial design of the module, the instructor sought to increase student engagement and interaction. This was attempted via a classroom assessment technique (CAT), a 2-minute paper was introduced at the conclusion of each class. Students were asked to write down 3 points they learned from class and 3 points of difficulty in separate columns. CATs were anonymous and reviewed by the author after class to identify trends in misunderstanding or recurring areas of difficulty. Student engagement and interaction was encouraged throughout classes via an in-class clicker system using Turning-Point software. The clicker system was used for in-class multiple-choice questions (MCQs) with at least 1 question every 5 min. These questions were linked to evaluate at least 1 of the module learning outcomes listed. Student answers could be graphically displayed within the PowerPoint in real time and gaps in understanding could be rapidly identified and remedied. At the conclusion of the module in 2018, the CATs were holistically reviewed and unsolicited feedback from students provided both in person after classes and by email at the conclusion of the semester was reviewed. This led to the decision to implement a flipped classroom for the module in 2019.

Implementation of a flipped classroom

Students were informed of the flipped classroom model in advance in 2019. Students were provided with video and audio recordings of the 2018 renal physiology classes, along with detailed PowerPoint slides, accompanying notes and peer-reviewed papers detailing concepts to be covered in class (1, 14, 20, 23, 36, 39, 63, 84). Student engagement with these pre-class materials was not monitored or assessed. Each hour of class time contained 10-12 problem sets and clicker questions, after which a brief 3-5-minute review of the topic was provided to clarify the right answer and how other answers were wrong. As in 2018, student perceptions was provided by the 2-minute paper CAT at the conclusion of each session.

Student survey on perceptions on the flipped classroom model

At the end of the second year (2019), student perceptions on the implementation of the flipped classroom model were assessed by a student survey. Paper surveys were dispersed by the instructor to students during the final 15 minutes of the concluding class of the module in 2019. All surveys were anonymous, students were not awarded any points for completion of the survey and participation was not mandatory (students were informed that if they did wish to participate that they could leave their survey blank). Surveys were collected at the conclusion of class by the course coordinator (not the instructor) who then shuffled the surveys and delivered them to the instructor. The survey asked 6 questions (5 questions were to be answered on a Likert scale (Strongly Disagree, Disagree, Don't Know, Agree, Strongly Agree), while the 6th question requested open feedback. The 5 questions to be answered on the Likert scale were as follows:

1. Q1: The renal physiology flipped-classroom model encouraged me to attend classes more regularly than those using solely traditional lecture-based formats.
2. Q2: The expectations for students in regards to their responsibilities to review material before class and actively work through problems in class was clearly explained in the flipped-class.
3. Q3: I achieved the desired learning outcomes more successfully in the renal flipped-classroom model than in other classes using solely traditional lectures.
4. Q4: I feel better prepared for answering assessment questions after taking part in a renal physiology flipped class than other modules using solely traditional lectures.
5. Q5: Would you agree / disagree that active and collaborative approaches such as the flipped-classroom model should be used more widely in 1st year medical school to enhance learning of physiology?

DESIGN OF A RENAL PHYSIOLOGY MODULE: YEAR 1 2018

The design of the renal physiology module in 2018 consisted on introducing several new elements, including classroom assessment techniques (CATs) and in class multiple choice quizzes (MCQs) through the use of a student response system (clickers). CATs are brief, formative assessment techniques that provide instructors rapid insight to student learning and understanding (2). Student response systems through clicker systems have been shown to improve student learning in medical school settings (32, 43, 58, 75). Upon approaching teaching of the renal physiology module for the 1st time in 2018, the author sought to develop a teaching mode that emphasized teaching for understanding (TfU). TfU consists of four main elements: generative topics, understanding goals, performances of understanding and ongoing assessment (10, 54, 55, 81). These four main elements, and how they informed the use of CATs and clickers in the renal physiology module is outlined below.

Constructing generative topics and learning outcomes (understanding goals)

Regardless of specific areas of instruction, all pre-clinical physiology lecturers want students to become critical thinkers and problem solvers (47), transferable skills they can carry into their clinical studies and practice, this is the generative topic of the module. This generative topic should be summarized in the learning outcomes of the module, which were not defined pre-2018. The first stage of the module re-design was to develop these learning outcomes (understanding goals within the TfU framework) and these were defined as follows:

At the end of the module, students should be able to:

a. Critically analyze and interpret scientific / clinical data relevant to the renal system.
b. Assess and diagnosis patient symptoms based on knowledge of renal physiology.
c. Design and implement appropriate treatment strategies for renal disorders.
d. Predict physiological / clinical outcomes of differing scenarios relating to renal function and disease.

For these learning outcomes to be effective, they must be publicly stated, explicit and linked to performance (7, 55, 81). In the initial stages of re-designing the module, it was postulated that these learning outcomes should be made public using the virtual learning environment (VLE), Web Campus, and class slides would be uploaded to the VLE at least 24 hours in advance, including a list of the desired learning outcomes.

Performances of understanding

In the early phases of designing the module in 2018, it became apparent that achieving performance driven learning outcomes would require active learning. This would engage students and allow them to demonstrate a key element of TfU, performances of understanding (10, 54, 81). Active learning has demonstratable positive effects on student success (29) and independent learning (38), and this is also true for physiology (12, 22, 49, 50, 69). In renal physiology, which is commonly thought of as challenging for students (70), active learning with interactive class discussions or demonstrations, student response systems, peer instruction and problem solving exercises can aid students in learning difficult concepts such as renal clearance and renal transport mechanisms (14, 19, 20, 36, 39, 56, 61, 63).

During the initial steps of module design, the author decided to integrate a clicker student response system into the class as a means to increase student interaction and active learning (30, 82). This had the additional benefit of acting as ongoing assessment, another key element of TfU. It was hoped that using a technology students were familiar with (students utilized this system in the previous block of classes), chances of success in promoting understanding would be enhanced (82). The clicker system was used for

in-class multiple-choice questions (MCQs) with at least 1 question every 5 min. Students were encouraged to confer with peers and work out complex problems in groups. A potential advantage of this was to develop collaborative learning while also allowing anonymous participation, removing inhibitions of shyer students.

Ongoing assessment

In addition to the integration of MCQs with clicker systems (a form of ongoing assessment and a performance of understanding), ongoing assessment was performed formatively using a classroom assessment technique (CAT). CATs are an effective means of increasing student engagement and gauging learning or understanding (2), affording the opportunity for course correction if issues arise. The CAT for this module (a 2-minute paper), was delivered at the conclusion of each class. Students were asked to write down 3 points they learned from class and 3 points of difficulty in separate columns. CATs were anonymous and reviewed by the author after class to identify trends in misunderstanding or recurring areas of difficulty. This allowed appropriate targeting of areas requiring revision during a review class near the end of the module. Importantly, if specific areas were recurring hotspots of difficulty, this might indicate an issue with instruction (flawed delivery, inappropriate time allocation to certain areas, insufficient active learning opportunities).

REDESIGN IN PRACTICE: 2018

To provide a specific example of how the new design of the module unfolded in practice, a single class session on the topic of "Control of glomerular filtration" from 2018 is described. This class involved students predicting how substances in the body are handled by the kidneys, specifically whether there is net secretion or reabsorption of these substances. These concepts center on glomerular filtration rate (GFR) and renal clearance, topics that are known to prove difficult for students (39, 63), but this can be alleviated by using interactive active learning techniques (36, 39, 56, 63). This is particularly relevant to medical students as these are key parameters used clinically to evaluate renal function. In the GFR class, the teaching session took place in a traditional lecture theater, with 38 students present.

GFR class learning outcomes

The content of the class was delivered via a lecture and small group exercises. The learning outcomes of this class were as follows:

- Define GFR and explain how it is auto regulated by local mechanisms.
- Compare and contrast how different hormonal inputs regulate GFR.
- Explain mathematically and in words how renal clearance can be used to calculate GFR.
- Predict the renal handling of a solute based on its clearance.

GFR Scenario 1 challenging concepts (Generative topic & understanding goals, TfU pillars 1 & 2)

As outlined above, GFR and more specifically renal clearance (volume of plasma cleared of a particular substance per unit time) is a slippery concept for students (39, 63, 70). Students are often intimidated by the mathematical calculations required to demonstrate understanding of this material. Also, the specific learning outcomes required students to make accurate clinical predictions of renal handling and function based on hypothetical clinical data. This leap from simple rote learning to active, higher order demonstrative performance-based understanding is often problematic (39, 63). However, it was intended that by having students work together on problems in class, that students displaying differing strengths may lead to new understanding among the class in a form of 'catalysis', where strengths in one student can assist in promoting other students to improve. It is well documented that students working together as peers often achieve learning outcomes more successfully than working in isolation, even if at the onset no student in the group knows the right answers (72). This shift from rote learning to critical thinking and problem-solving circles back to the generative topic of the course as outlined above in the TfU framework.

GFR Scenario 1 preparation

Throughout the class, students were engaged with 1-on-1 Q&A and group clicker questions scenarios. Initial MCQs centered on revision of topics from previous classes (define GFR generally, how changes in GFR affect water reabsorption in the proximal nephron, how GFR is controlled by local autoregulation). It was predicted that the most difficult area of the 60-minute class would be in the last 25 mins (after a 5-minute break), where the mathematical equations relating to renal clearance were first encountered. These equations were introduced (*Renal clearance = excretion rate of X (mg/min) / [X] plasma (mg/mL)*) and followed by an outline of how they how they are clinically applicable to assess renal function (by comparison of clearance values with the precalculated clearance value of inulin or creatinine, where clearance rate is equal to GFR (70)). Students were told how clearance informs how a substance is handled in the kidney, i.e. if there was net reabsorption or secretion of the substance: if the clearance of a substance was less than GFR (calculated from inulin or creatinine clearance) there was net reabsorption of that substance, whereas if the clearance of a substance is greater than GFR there was net secretion of that substance.

GFR Scenario 1 application

Students were then presented with 2 hypothetical scenarios. In scenario 1, students were asked how glucose renal clearance would be affected in diabetic patients (as shown in Fig. 1A). Students were asked to select from 3 answers using a student response 'clicker' system (anonymously). Students were given 2 minutes to confer in small groups and select a correct answer. Scenario 1 was deliberately difficult. Due to the complicated handling of glucose in the kidney under states of diabetes, it is unlikely that students would be able to answer this question correctly by thinking conceptually about the answer. Normally, all glucose entering the nephron is reabsorbed and thus the clearance of glucose is 0 mL/min (as none of the plasma has been cleared of glucose). However, under conditions of diabetes, far more glucose than normal enters the nephron due to hyperglycemia and glucose transporters in the nephron become saturated, meaning that some glucose will not be reabsorbed and remain in the nephron. As glucose clearance is normally zero, students were confused as to how to approach the question: would glucose clearance go up, down or not change in diabetes? (assessed by a show of hands who was confident in a right answer). Students

A Scenario 1: in diabetic patients, will glucose clearance still be 0ml or will it change?

1. Glucose clearance remains the same.
2. Glucose clearance increases.
3. Glucose clearance decreases.

B Scenario 2: GFR calculated as creatine clearance of 100 ml/min. Predict if there will be net reabsorption or secretion of urea and penicillin.

1. Net urea reabsorption, net penicillin secretion.
2. Net urea secretion, net penicillin reabsorption.
3. Net urea reabsorption, net penicillin reabsorption.
4. Net urea secretion, net penicillin secretion.
5. Net urea reabsorption, no net penicillin secretion or reabsorption.

Fig. 1. Interactive exercises used during class on GFR in 2018.
A Question relation to the effect of diabetes on renal clearance values used in GFR lecture which student answered using clickers. Option 2 is the correct answer.
B Question relation to the effect of urea and penicillin reabsorption or secretion based on renal clearance values used in GFR lecture which student answered using clickers. Option 1 is the correct answer.

were then reminded that a key learning objective of the class was to predict renal handling by calculating clearance values with the appropriate equations: *Renal clearance = excretion rate of X (mg/min) / [X] plasma (mg/mL)*. Students were encouraged to arrive at a correct answer by using the equation with hypothetical data. As non-diabetic patients do not excrete glucose (it is entirely reabsorbed) the end value from this equation will always be zero. However, in a diabetic patient, there is some glucose excretion due to glucose transporter saturation in the nephron. Thus, the end value from the clearance equation for these patients will always be above zero, regardless of how low the excretion rate. The correct answer can thus be quickly worked out empirically using clearance calculations. Therefore, the quickest way students could arrive at the correct answer would be to work their way through the equations that were presented in the preceding few minutes, demonstrating their importance in learning the overall topic. Importantly, this also linked to the second pillar of the TfU framework (understanding goals), as in this case, the teaching of the subject was directly linked to a class learning outcome (understanding goal).

GFR Scenario 1 student interpretation (Performances of understanding, TfU pillar 3)

After the 2-minute conferring time, the clicker responses were collated but not yet presented to the class. 6 students were cold-called to state and justify their answer. In 2 such instances, students stated that they picked the wrong answer (this was not revealed) and they explained that as they were thinking through the problem conceptually and not mathematically, they reached the conclusion that they did. The remaining students selected the correct answer, however all of them qualified their statements with something akin to:

> I'm not sure if this is right, I feel like it's not but it's what the numbers tell me.

In these cases, students accurately worked their way through the mathematical equations shown previously and arrived at a counter intuitive but correct conclusion. The clicker results were presented to the class (72% of students selected the correct answer) and it was emphasized how important it was to understand the equations just shown, as this example clearly demonstrated that one cannot rely on broad conceptual ideas alone for all cases, as under pathophysiological states where the body is malfunctioning, normal rules do not necessarily apply. This session encapsulated the generative topic of the course within a TfU framework (all pre-clinical physiology lecturers want students to become critical thinkers and problem solvers), and was also clearly linked to the 3rd TfU pillar, performances of understanding. In order to arrive at the right answer, students needed to work their way through the mathematical equations in the class to arrive at a correct conclusion. A correct answer would not have been arrived at by simple rote learning, and thus in order to demonstrate understanding, students could not simply repeat the equations to the instructor verbatim. Instead, students needed to demonstrate their understanding by working with and applying their learning, rather than simply reproduce a stock answer.

GFR Scenario 2 application (Performances of understanding, TfU pillar 3)

In scenario 2, where students were required to demonstrate further performances of understanding (3rd TfU pillar), they were presented with 2 separate hypothetical data sets. The students were presented with the renal clearance values of two different substances, urea and penicillin, both of which are handled in opposing fashions by the kidneys in terms of their net reabsorption or secretion as described by Silverthorn, (70). Students were then asked to select 1 of 5 options (Fig. 1B) to reflect their predictions using the clickers and were given 5 minutes to confer with their classmates or ask / discuss questions with myself. To correctly answer this question, students needed to demonstrate that they could apply knowledge of several different concepts. They needed to have a firm grasp of the definitions of reabsorption and secretion in the renal context, they needed to understand the mathematical basis of renal clearance to interpret the numerical values in these examples and they needed to accurately predict the renal handling of each substance based on these values, a common application of evaluating the renal handling of a material either clinically or in research studies. Thus, accurately

demonstrating a grasp of these integrated concepts should result in a successful performance of understanding.

GFR Scenario 2 student interpretation

At the conclusion of the 5 minutes conferring time, students finalized their selections and were once again cold called to state and justify their answers to the class. In this engagement, all students selected the correct answer and logically explained why they had selected their answer. Students could also explain why other selections were incorrect (the mathematical equation would not lead to that conclusion; the definitions of reabsorptions and secretion would need to be altered / reversed if certain answers were correct etc.). Upon revealing the results of the clicker responses, 87% of students selected the correct answer.

Post-teaching reflections: Year 1 2018

Use of clicker systems (Ongoing assessment, TfU pillar 4)

The 4th pillar of the TfU framework that was threaded throughout this module was ongoing assessment. Assessment of learning and student perceptions of different approaches is vital to TfU success. This assessment took place within each class through the use of the clickers and CATs. While clickers allowed for active engagement and interaction with students, there were intrinsic limitations to this approach. One of the advantages of clicker questions was that they were anonymous (unless a student was asked to justify their answer afterwards), however this also meant it was difficult to track the answers of individual students. Even if a high percentage of students (>85%) consistently selected the correct answers, there was no information on who the remaining 15% were. Thus, it was unknown if there was a cohort of students that continuously struggled and needed intervention, or if the 15% represented a spread of students that varied between different questions. An excellent student might still get a question wrong every now and again, and did not necessarily warrant a red flag of a lack of understanding in general. Alternatively, there could be a minority of students that were drowning in the material, consistently selecting incorrect responses.

The use of clickers required high levels of student concentration; thus regular breaks were essential. 5-minute breaks were instigated every ~25-30 mins, during which students were encouraged to interact with the instructor 1-on-1 or in small groups to discuss the material just covered. Unexpectedly, many students were eager to forgo a break and appreciated the opportunity to discuss material and ask questions. Often, a line quickly formed at the top of class of about 5-6 students who wished to speak with the instructor. Each student was taken aside for privacy and their question or concern discussed for ~1 minute. In most cases, this was sufficient time to clarify any issues. When this was not adequate, time was organized for the student and instructor to meet after class to explore their query in detail. After the break, queries were related back to the class (while not ascribing names). The question was reviewed for 1-2 mins before moving on. It was thought that if one student had an issue or was confused about something enough to ask a question, it was highly likely that a more introverted student had the same issue but would hesitate to approach the front of the class during the break. Thus, feedback from the more extroverted students was used to help other students that might have similar queries.

Use of 2-minute paper CAT (Ongoing assessment, TfU pillar 4)

The 2-minute paper CAT students completed at the end of every class was revealing. In most cases, concepts and content that students noted as challenging or unclear were almost exclusively areas not associated with an active learning exercise (such as the clicker responses segments or short cold calling Q&A / discussion). This was unexpected as active learning exercises were included for areas that were noted to prove difficult for students in previous years, such as renal clearance (36, 39, 56, 63). As a result, less time was devoted to what were perceived to be easier to understand areas. This led to a re-evaluation of assumptions of what students may find obvious or easy to follow in a renal physiology class, and encouraged a revision of how these topics might be taught in subsequent years. Clearly, there were portions of material for which there was insufficient or ineffective coverage. In future classes, perhaps other active learning exercises (such as small group discussions or game learning) should be considered to address these gaps, and not presume what students may or not find easy based on a singular instructor's preconceptions of the difficultly of the in-class material.

A class late in the semester was a 60-minute review. On the very first day of class, when introducing the concept of the 2-minute paper, it was decided to make explicitly clear that in the upcoming review class, only topics highlighted by students in the 2-minutes papers would be reviewed. From personal experience, students who may not grasp a concept in class may not consider asking for clarification or help, as they may predict that if it's relevant for summative assessment, the topic will be eventually revisited in a later review. Thus, for the review class, rather than giving a summary of lectures, students needed to state what they wanted reviewed via the 2-minute papers. If they didn't think it was important to mention on their 2-minute paper, it was not covered in the review class. Informal feedback suggested that students appreciated this honest explanation of what was expected of them, feeling it was a genuine student-centered approach where they had to take ownership of their learning.

Student feedback (Ongoing assessment, TfU pillar 4)

Student comments provided informally to the author (unsolicited feedback provided both in person after classes and by email at the conclusion of the semester) showed the following key points.

- Students responded positively to the active engagement techniques used in class.
- Students noted that clicker questions and opportunities for discussion made classes more interactive and enjoyable than standard lectures classes.
- Some students did not appreciate that clicker questions were not uploaded to Web Campus prior to class, as they felt unprepared to answer them when presented in class.

In regards to the 3rd point above, the rationale for this choice on the authors part, was not only to encourage attendance by having solely in-class content, but also to generate spontaneous bursts of active learning. It was thought that uploading activities before class would mean that performance of these activities in class would be reduced to a recital, and would not fully engage students. On reflection, in this 1st semester, Web Campus was primarily used as a content repository. In subsequent years,

perhaps Web Campus could be used to appropriately prime students for active learning in class, for example by establishing online discussion boards. This might be accomplished by providing students with a hypothetical case study which they discuss on Web Campus, and then have a brief overview of that topic for 1-2 mins at the start of the relevant class. Due to restrictions within the medical school for what can be used for grading purposes, it would not be possible to assign even a marginal grade incentive for participation in this online discussion. For this reason, a concern is that there might be little interaction on Web Campus for a non-mandatory exercise.

Conclusions: Year 1 2018

1. Clicker systems allowed for instant feedback on performances of understanding and allowed for rapid course correction if needed.
2. Students appreciated the clear purpose of the 2-minute CAT and welcomed the opportunity to contribute to content covered in the end of semester review class.
3. The anonymous nature of the clicker MCQ setup meant that it was not possible to track the progress of individual students, thus any student that consistently struggled could not be identified for intervention.
4. The 2-minute paper CAT revealed that areas without an active learning exercise were often deemed as the most unclear by students, thus preconceptions of what students may find easy or hard should be reevaluated.
5. Certain students were unsettled by the inclusion of lots of active learning exercises, suggesting that priming students to these expectations online via a VLE and providing demonstrations of exercises that will be covered in class (possibly via discussion boards or instructional videos) would be beneficial in the future.

FLIPPING A RENAL PHYSIOLOGY MODULE: YEAR 2 2019

Upon reviewing student feedback from 2018, it was decided to include more active learning exercises in the renal physiology module for the following year in 2019. This was envisioned as being a more student (learner)-centered rather than an instructor centered approach. In a learner-centered approach, the instructor assists students with accessing and engaging with content and spending more time 'on task' in class (9). In this case, there is a shift from instructors allocating time for lecture preparation to time planning ways to help learners achieve learning goals and outcomes for the course, which in this case would be accomplished by increasing the amount of time students spent in class working together on problem sets relevant to Step 1 exams. In addition, increased time spent working through problem sets in class would further enhance the TfU framework of the module. Flipped classrooms have been proposed to increase problem solving and critical thinking in medical school students (74), which would support the generative topic of the module in question (TfU 1st pillar). As the module learning outcomes (understanding goals, TfU 2nd pillar) were active in nature, by implementing a flipped classroom, where students used clickers and CATs to work through problem sets, students would be given more opportunities to demonstrate performances of understanding (TfU 3rd pillar) than in previous incarnations of the module and the instructor would therefore be afforded more formative assessment of student learning (ongoing assessment, TfU 4th pillar) as well as student perceptions of different teaching approaches.

However, increasing time spent in class developing active learning would have consequentially resulted in a decreased amount of time covering required material. With this consideration, it was decided that the 2019 teaching of the module would be via a flipped classroom model. In our flipped classroom for the renal physiology module, there was no lecture teaching of content. Instead, video and audio recordings of the previous year's lectures, as well as the accompanying PowerPoint slides and reading material were made available via the VLE 1 week ahead of scheduled class time. Students could access this content in their own time (asynchronously) outside of the class timetable. During the class timetable, no new lecture material was covered. Instead, during the live sessions (synchronous session) students completed short problem sets and interactive Q&A sessions based on that weeks material for the entire duration of the class. This was based on well-established models of flipped classrooms, where students review class content prior to coming to class and then apply their knowledge of that material in active learning exercises in class (45). From the literature, this approach helps to bridge the gap between a need to cover all appropriate material while maximizing time spent on active learning in class (31, 34).

Flipped classroom pre-class strategy

For the teaching of the institution 1 renal physiology module in 2019, students were informed of the flipped classroom model in advance and were told that the goal of the flipped classroom was to enhance their problem solving and critical thinking skills (generative topic TfU pillar 1). Students were provided with video and audio recordings of the 2018 renal physiology classes via the VLE, along with detailed PowerPoint slides, accompanying notes and peer-reviewed papers detailing concepts to be covered in class (1, 14, 20, 23, 36, 39, 63, 84). Students had access to pre-class materials 1 week in advance of the in-person class session. Students were notified by email when materials were uploaded. In these communications, students were informed of the type and number of files uploaded (video, audio, text) and provided with a suggested workflow order to engage with the materials. It was made explicit to students that the in-person classes would not cover new material but would instead consist of problem-solving sets linked to module learning outcomes (understanding goals TfU pillar 2) that would require their interactive engagement (performances of understanding TfU pillar 3). Students were advised that their understanding would be formatively assessed by MCQs, clickers, Q&As and CATs (ongoing assessment TfU pillar 4). Students were invited to email the instructor with questions ahead of class. Student engagement with these pre-class materials was not monitored or assessed.

Flipped classroom in-class strategy

Each hour of class time contained 10-12 problem sets and clicker questions, after which a brief 3-5-minute review of the topic was provided to clarify the right answer and how other answers were wrong. While discussion boards via the VLE were initially considered as an approach to also engage students with material outside of class, this was not implemented as data suggests that such discussion boards only increase engagement prior to summative assessments (60). As in 2018, student perceptions were provided by the 2-minute paper CAT at the conclusion of each session.

Student perceptions of the flipped class model were assessed at the end of the semester using an anonymous, 6 question survey as outlined in the Methods section.

Post-teaching reflections: Year 2 2019

Student perceptions of the flipped classroom model

The benefits of the MCQ clicker systems, frequent breaks and the 2-minute paper have been discussed in detail in the section on post module teaching for 2018. Similar insights were gleaned in 2019 with these approaches and readers are referred to the sections above for greater detail. As the major re-design of the module between 2018-2019 was the use of the flipped classroom, post-teaching reflections will focus on the survey students completed at the end of the semester detailing their experiences in the flipped class.

27 out of 70 students chose to complete the survey and their responses are shown in Fig. 2. The first question on the survey addressed how the flipped class affected attendance (Q1: The renal physiology flipped-classroom model encouraged me to attend classes more regularly than those using solely traditional lecture-based formats). This question was asked as there was a distinct drop in attendance compared to 2018, (6-8 students present vs 20-25 students for the first 3 classes of the module). This drop in attendance was also noted for other classes throughout the 1st year curriculum in 2019 and follows trends of consistently falling attendance rates for pre-clinical classes nationally (85). Of course, for the flipped classroom to work, attendance is crucial (61). 77.7% of students either agreed or strongly agreed that the flipped class encouraged them to attend classes more regularly (Fig. 2, by the end of the module attendance steadily increased from 6-8 per class to 25-27 per class).

The majority of students (81.4 %) also agreed that the expectations for students in regards to their responsibilities to review material before class and actively work through problems in class was clearly explained, as per Q2 (Fig. 2) and 85.2% of students agreed that the flipped class helped them achieve the class learning outcomes more successfully than other classes using lectures (Q3: Fig. 2). The same % of students also agreed that they felt better prepared to answer assessment questions after using the flipped class model (Q4: Fig. 2) and 96.3% of students agreed that models such as the flipped classroom should be used more widely in 1st year medical schools (Q.5: Fig. 2).

Student comments in the open feedback question from the flipped classroom survey was thematically analyzed and responses were summarized in 4 themes i) effects on attendance, ii) student collaboration and interaction, iii) opportunity to practice problem sets and iv) recommendation of a blended approach to teaching. The thematic grouping of student comments, as well as general feedback in displayed in Table 1.

Most of the student comments suggested that the flipped classroom did encourage them to attend class more regularly, as encapsulated by the comment below.

> Most of the time this encouraged me to attend classes more, except during busy weeks where I didn't feel like I could properly prepare to come to a flipped lecture, so I didn't come in as much as normal.

Table 1. Student feedback on the implementation of the flipped classroom in 2019.

Theme 1: Attendance	"I almost never go to class. This was the only class I religiously went to. This was awesome, thank you."
	"It did increase my desire to attend for fear of missing on informative collaboration. The collaborative aspect was the most beneficial and would be good to use more frequently."
	"Most of the time this encouraged me to attend classes more, except during busy weeks where I didn't feel like I could properly prepare to come to a flipped lecture, so I didn't come in as much as normal."
	"Everyone works own pace. So if the lecture is on something they haven't themselves reached, they wouldn't come."
Theme 2: Collaboration & Interaction	"I like the interactive format."
	"Talking in groups and then going over the answers is helpful."
	"I really enjoyed how students were called upon and given time to explain their thoughts and how we were not told if we were correct or incorrect immediately. I would have liked to see a faster pace but I'm sure the pace was to accommodate other students."
	"Some students didn't like being 'hounded' when they didn't know a concept. I did like being called on randomly so I'm always engaged and the geniuses of the class don't do it all.
Theme 3: Problem Solving & Practice Questions	"I think the flipped classroom experience is very positive in the 1st year setting because if allows us to practice Step 1 style questions."
	"All of the practice with questions was very helpful."
	"For renal physiology, it was useful as the questions were good to test application of knowledge, with a foundation already in place."
Theme 4: Blended Teaching	"It would have been nice to have more of a review of key concepts prior to starting the lecture rather than starting in questions immediately."
	"I think a combination would be good. Maybe have a quick 15-minute review at the start of a flipped lecture then go into questions for the rest of the time."
	"I wish that there was both. I feel that I have missed information along the way because I am relying more on videos than lectures, which I don't like."
Theme 5: General Feedback	The questions opened my eyes that I need to study the material more."
	"I did not have enough background in the beginning, but once I was familiar with the material it helped me."
	"I thoroughly enjoyed the flipped-classroom model because it forced me to think about the concepts I learned at home."
	"It helped me realize deficiencies in my learning."
	"Flipped classroom is my favorite way to learn."
	"I think it's a really good idea with a lot of learning outside and inside class, because you can come to class and solidify and test knowledge with questions rather than just another pass through the material."

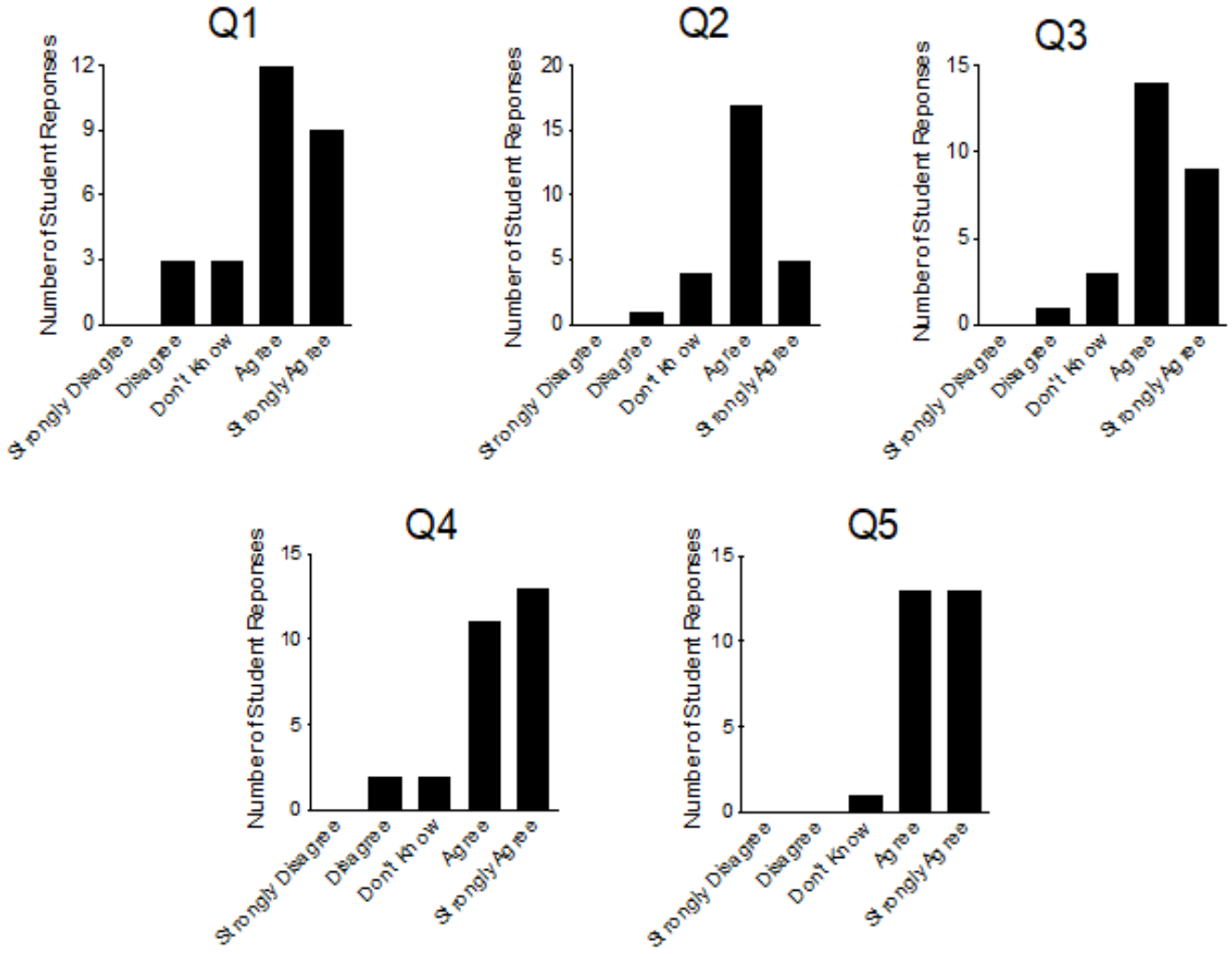

Fig.2. Student perceptions on the implementation of a flipped classroom model for renal physiology (2019).
Summary data showing student responses to a 5-part student survey on the use of a flipped class model for renal physiology (2019). Students were asked to select responses on a Likert scale. Q1: The renal physiology flipped-classroom model encouraged me to attend classes more regularly than those using solely traditional lecture-based formats. Q2: The expectations for students in regards to their responsibilities to review material before class and actively work through problems in class was clearly explained in the flipped-class. Q3: I achieved the desired learning outcomes more successfully in the renal flipped-classroom model than in other classes using solely traditional lectures. Q4: I feel better prepared for answering assessment questions after taking part in a renal physiology flipped class than other modules using solely traditional lectures. Q5: Would you agree / disagree that active and collaborative approaches such as the flipped-classroom model should be used more widely in 1st year medical school to enhance learning of physiology.

Student remarks suggested that one of the key reasons that they attended class more regularly in the flipped classroom model was the increased opportunity to engage with their classmates and collaborate on working through problems.

> It did increase my desire to attend for fear of missing on informative collaboration. The collaborative aspect was the most beneficial and would be good to use more frequently.

Students appreciated the chance to work in pairs or small groups for much of the class time to work through problems and their feedback suggested that the interactive format that allowed them to apply their knowledge:

> I think it's a really good idea with a lot of learning outside and inside class, because you can come to class and solidify and test knowledge with questions rather than just another pass through the material.

It is also important to note that while the flipped class was well received overall, many students suggested that a blended approach of flipped classes and lectures may be more beneficial.

> I think a combination would be good. Maybe have a quick 15-minute review at the start of a flipped lecture then go into questions for the rest of the time.

These comments suggest that in a future re-design of the renal physiology module, a combination of short lecture review presentations and flipped classroom active learning should be considered (Fig. 3).

Conclusions: Year 2 2019

1. Student attendance was positively impacted by implementation of a flipped classroom model.
2. Students noted a positive perception of the interactive, collaborative learning opportunities that flipped classes afforded.

3. The opportunity to apply knowledge through problem sets and Q&A in class was very positively received.
4. Feedback indicated that while the flipped class was well received overall, many students suggested that a blended approach of flipped classes and lectures may be more beneficial.

DISCUSSION

In this paper, we have described the evolution of a renal physiology module for 1st year medical school over a 2-year period, with a view to capturing author reflections and student perceptions on the use of active learning and flipped classrooms. We found that students positively welcomed the introduction of active learning techniques such as clicker response systems and CATs into the renal physiology module. This led to flipping the module entirely in the 2nd year which was also positively received by the majority of students, who noted the increased time spent on practicing problem sets and collaborating with peers in class. In the literature, the use of flipped classrooms is noted to have several positive outcomes for students. Previous studies suggested that flipped classes improve academic success and exam scores due to promotion of active learning (13), and narrows the performance gap between low and highly achieving students (34, 83). From studies of physiology modules, including renal physiology modules, flipped classrooms are implicated in not only improving grades (52, 61, 64, 78), but also promoting independent learning strategies (48) and are positively received by students generally (33).

From the perspective of the TfU framework, flipped classrooms have been proposed to increase student problem solving and critical thinking skills (74) (TfU 1st pillar). As the renal physiology module learning outcomes (understanding goals, TfU 2nd pillar) were active in nature, by implementing a flipped classroom, students were able to demonstrate performances of understanding more frequently than in a traditional lecture-based classroom (TfU 3rd pillar). In addition, flipping the classroom meant that the instructor was afforded more opportunities for formative assessment of student learning through the increased use of MCQs, clickers and student Q&A (ongoing assessment, TfU 4th pillar).

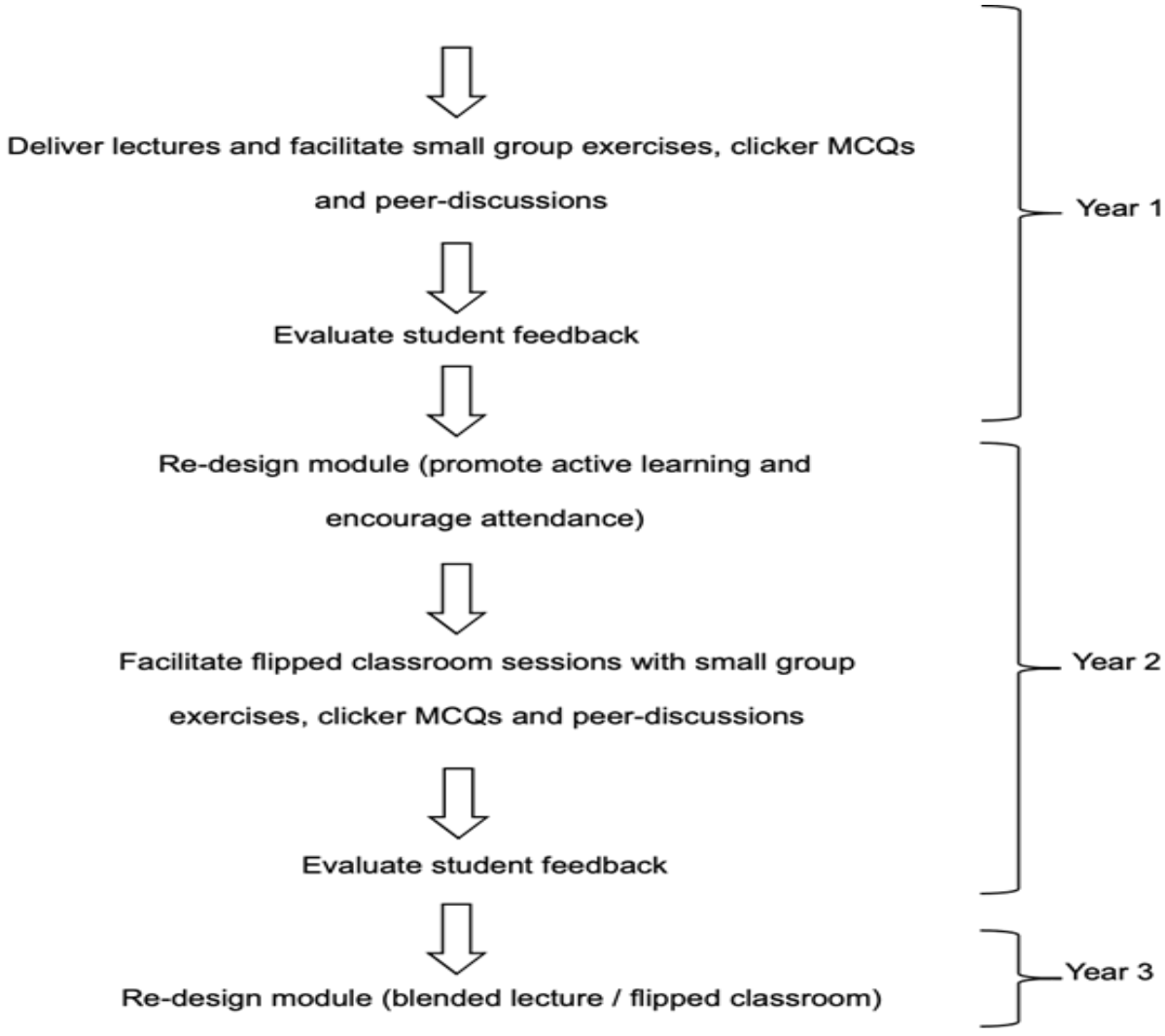

Fig.3. Evolution of the design and implementation of a renal physiology module.

Student perceptions on flipped classrooms (attendance)

Perhaps the most important aspect of our study was the insight gleaned from the student surveys at the conclusion of year 2. In particular, the open feedback question yielded a collection of responses that provide important information on the student experience with flipped classrooms. This feedback was thematically divided into 5 headings; i) attendance, ii) collaboration & interaction, iii) problem solving and practice questions, iv) blended teaching and iv) general feedback (Table 1).

Attendance is a critical parameter for student success in 3rd level education and studies of medical school and undergraduate physiology students have shown that there is a correlation between class attendance and summative academic performance (16, 17, 73). However, despite this, it has been noted that the class attendance of pre-clinical medical students in the U.S. has been steadily decreasing in recent years (85). Thus, instructors may need to develop new strategies for encouraging in-person attendance to ensure students are afforded the maximum opportunity to succeed. Flipped classrooms have been proposed as one mechanism that can enhance student attendance (37, 76, 79). Overall, our results indicate that flipped classrooms encouraged students to attend class more regularly, suggesting that flipped approaches might be beneficial to other physiology / medical modules that have issues with regular attendance. This fact that was supported by the quantitative student survey responses (Fig. 2) and noted in other studies of medical and dental students (37, 76, 79). Certain students noted which specific factors that might affect their attendance, with one student noting;

> It did increase my desire to attend for fear of missing on informative collaboration. The collaborative aspect was the most beneficial and would be good to use more frequently.

While our quantitative data suggest that the flipped classroom improved attendance, student responses here also provide possible explanations for how it might perturb attendance. In particular, engagement with pre-class materials and being adequately prepared were viewed as a pre-requisite for attendance and if students viewed that they had no sufficiently engaged with the material before class, or were behind with catching up with material, they were less likely to attend.

> Most of the time this encouraged me to attend classes more, except during busy weeks where I didn't feel like I could properly prepare to come to a flipped lecture, so I didn't come in as much as normal.

Student perceptions on flipped classrooms (collaborative learning)

Students responded positively to the interactive format that the flipped classroom provided and welcomed the opportunity for collaborative learning with their peers. On a practical note, students were enthusiastic to practice Step 1 style questions, as exclaimed by one student.

> I think the flipped classroom experience is very positive in the 1st year setting because it allows us to practice Step 1 style questions.

While the interactive format was well received, students responded differentially to certain interactive approaches, such as cold calling students to answer questions or voice their opinion on a discussion. This dichotomy is highlighted by the differing responses from students below:

> I really enjoyed how students were called upon and given time to explain their thoughts and how we were not told if we were correct or incorrect immediately. I would have liked to see a faster pace but I'm sure the pace was to accommodate other students.

> Some students didn't like being "hounded" when they didn't know a concept. I did like being called on randomly so I'm always engaged and the geniuses of the class don't do it all.

Why exactly students differed in their perceptions of this approach is currently unknown. It is possible that differing student personalities play a role here as more extroverted students or those strong in linguistic intelligence may have felt more comfortable in answering questions. Additionally, perhaps the level of pre-class engagement with the reading material may play a role in how receptive students are to answering cold questions in class. These possibilities are interesting but warrants further investigation in future studies. Students may have felt pressure to always have the 'correct answer' when asked a question and were thus hesitant to either attend or participate in class if they were unsure of any of the material. This should be carefully considered, as having the 'freedom to fail' is an important aspect of higher order learning. However, due to the nature of their future profession, medical students feel more pressure to be "right" in their in-class sessions as they are cognisant that if they are wrong in their profession, there is a lot more on the line (in addition to the normally hyper-competitive nature of medical school itself). Furthermore, medical students often perceive assessment, even ongoing formative assessment (a key pillar of TfU) as a source of personal anxiety (53, 62). Changing student attitudes in this regards will require making the formative nature of the in-class assessments explicit (as set out by TfU frameworks), as well as creating a safe learning environment for students (for example by placing more emphasis on formative feedback rather than summative grades or by allowing students to demonstrate understanding in multiple forms (verbalization, drawing diagrams, use of alternative media (57)) in which they can feel comfortable to explore their application of concepts and techniques without feeling pressure to always be 'right'.

Student perceptions on flipped classrooms (blended learning)

Students highlighted that a blended approach to teaching, rather than a purely flipped classroom might be optimum for their learning. Students praised the opportunity to work together in class and practice answering questions but also suggested that a combination of lectures and flipped classroom approaches would be the best of both worlds, as highlighted by one student;

> I think a combination would be good. Maybe have a quick 15-minute review at the start of a flipped lecture then go into questions for the rest of the time.

Thus, while the benefits of flipped classrooms were apparent to many students, as they noted how this approach helped them to "*realize deficiencies*" in learning and made them "*think about the concepts*" rather than simply get "*another pass through the material*", in future redesigns a blended approach could be attempted. This might include, as one student suggested, a brief 15-minute review

of material at the onset of class before launching into the problem sets. How such a blended approach could be designed and implemented should be informed by feedback from students (possibly though focus groups) in future studies. Taken together, the possible benefits of flipped classrooms such as collaborative learning could be viewed as a potential high impact practice (HIP) gain. HIPs are teaching approaches that yield a significant benefit for students and enable a deep and effective learning experience for students (44). Flipped classrooms and active learning approaches in general, can help students more effectively demonstrate performances of understanding as part of a learning community (within their class) and collaborate with their peers in a common intellectual experience to a greater degree than traditional lecture based classes, and thus overlap with many identified HIPs (44). Such potential student benefits place the onus on instructors to consider integrating such approaches in their own course design.

Flipped classrooms and active learning

It is interesting to speculate whether the positive perceptions of the flipped classroom in our own paper are due to the flipped class per se, or merely the use of increased active learning approaches generally. In a study examining the effects of an active flipped classroom vs. An active non-flipped classroom, it was found that student learning of both low-level and deep-level concepts was the same across both approaches, suggesting flipped classes instill their positive benefits by increasing class time spent on active learning and not necessarily by allowing students to review material prior to class (42). Whether this also pertains to physiology students should be examined closely in future studies. This is also tied into another unanswered question: of those who attended class, what % of students reviewed the material prior? While this was not examined in the 2019 module, a future cohort of students could be evaluated on how much time was spent reviewing material prior to class and whether there are any correlations between pre-class preparation time and perceptions on the utility of the flipped class model. The flipped classroom model only works if students prepare for the active class sessions by engaging with materials prior to class (13, 24, 31, 61). If this does not occur, active learning would not be possible as students would have no background to engage in active exercises, as a result the class would resort to teaching for coverage rather than active engagement.

It should also be noted that the active learning techniques we employed in this study (clickers, CATs) only provide a momentary snapshot of student learning. In order to truly gauge the effects of these interventions on student learning (as opposed to student perceptions evaluated in the current study), student learning would need to be systematically assessed over time as these techniques were introduced. Unfortunately, a comparison of summative scores in final exams across the different years of the module was not possible due to restrictions surrounding the use of past student scores at the institution. However, in future studies, perhaps student learning could be more systematically assessed by a formative assessment at the end of the module that assessed students on the critical thinking and problem skills the active learning approaches would hopefully instill. However, in order to judge the effectiveness of the approaches used in this study (clickers, CATs, flipped classes), this formative assessment would also need to be delivered to a cohort of students that were taught almost exclusively by lectures as a control. As described by Felten, a key recognition in the scholarship of teaching and learning (SoTL), is that learning does not exclusively equate to summative or even formative assessment performance, but also positive changes in student perceptions or habits in approaching learning (28). With this in mind, another possibility would be to hold focus groups with students at the conclusion of the semester to discuss how their attitudes to active learning or flipped classes may have changed as a result of taking part in our module. (24, 26, 50, 59, 77). This could be a valuable way to ascertain how students perceive active learning over the course of a module, as it may change as the module progresses. It has been reported that at the onset of a module or course, students can perceive active learning negatively due to the greater cognitive effort it requires over rote learning (50). However, as students become more familiar with active learning, they may perceive such approaches as being beneficial and welcome the opportunity for more active learning in the future (18).

Flipped classrooms and online student engagement

Our findings and reflections are pertinent given the global pivot to online education during the COVID-19 pandemic. With emergency transitions to online teaching, many instructors struggled to engage their students in an online environment, as well as being unsure of whether to use synchronous or asynchronous online teaching (21, 27, 46, 51). From the literature, boosting student engagement with online material often comes as a result of interactive teaching, coupled with active learning (3-5, 24, 25, 35, 52, 65). The response from students in our study suggested that many of them would prefer a blended approach to learning, with a mixture of lectures and active learning centered classes. Such a blended approach (a mix of lectures and active sessions opposed to a blend of online and face to face teaching) might lend itself to the online teaching environment in a virtual flipped classroom. In this scenario, lecture material could be recorded asynchronously, while live sessions could be used for active application of this material in small groups in breakout rooms in Zoom or Microsoft Teams. Such an approach could decrease the known downside of 'Zoom' fatigue which might impact online modules solely delivered synchronously (80), while also giving students the freedom to access material in their own time and also allowing opportunities for active learning and collaboration online.

While some instructors may prefer to deliver all content asynchronously to decrease time spent on online teaching platforms such as Zoom or Microsoft Teams down to a minimum, recent evidence suggests that a combination of asynchronous and synchronous material might be more beneficial for students, with some synchronous teaching (with active learning components) being essential for enhancing student engagement and developing higher order analytical skills (15, 66, 71). Such blended approaches are shown to be positively received by students in the medical fields, including in physiology subjects and can even improve summative exam performance (5, 25, 35, 52, 65). Furthermore, evidence from physiology undergraduate students in Australia has demonstrated that classes taught in a similar flipped manner to that described in this paper (asynchronous teaching of recorded lectures followed by active classes in small groups working through problems), were able to more easily transition to successful remote learning (using Zoom breakout rooms for small group exercises in live sessions) than those that relied on

traditional lectures alone (6). This was accredited to the active learning resources and exercises required for a successful flipped classroom being readily available to successful engage students in the online space (6).

Incorporating TfU into renal physiology modules

We set out to design the renal physiology module along the principles of TfU. By implementing the flipped classroom model, we linked to the 4 TfU elements; generative topics, understanding goals, performances of understanding and ongoing assessment (10, 54, 55, 81). Students were informed of the flipped classroom model in advance and were told that the goal of this approach was to enhance their problem solving and critical thinking skills (generative topic TfU pillar 1). In our design, we ensured that in-person classes would focus on problem-solving sets linked to module learning outcomes (understanding goals TfU pillar 2) that required interactive engagement (performances of understanding TfU pillar 3). Student understanding was formatively assessed by MCQs, clickers, Q&As and CATs (ongoing assessment TfU pillar 4). By working together in groups to solve problems in the flipped classroom, students were practicing critical thinking and problem solving, part of the generative topic of the module and course. The understanding goals or learning outcomes were made explicit to students and they were able to have more opportunities for performances of understanding in the active sessions in the flipped model. The use of the student response system and CATs also allowed for ongoing assessment of students, while also being tools for active learning themselves.

LIMITATIONS AND FUTURE STUDIES

It should be noted however, that our study was intrinsically limited and our survey to ascertain students' perceptions of the flipped classroom model was only preliminary. While our survey results indicated that students perceived the flipped classroom approach as being beneficial to their learning and positively impacted on their attendance, the reasons behind these responses were not explored in depth. For example, it is unknown how much students interacted with the pre-class materials before coming to class. It would be interesting to learn if there was a correlation between the amount of time students spent engaging with pre-class materials and their subsequent engagement (or positive perception of) the interactive in-class exercises in the flipped classroom. In addition, while some students stated that overall, the flipped classroom model positively impacted their attendance, it is currently unknown what were the individual factors that encouraged students to attend the in-class sessions. Was it an opportunity to practice Step 1 style questions? Was it the collaborative learning with peers? Was it the chance to ask questions of the instructor or was it in the hope of diffuse learning by simply being in an in-person learning environment? While the student responses provide hints to this, these points require further investigation (for example, one student noted a desire to attend due to collaborative learning opportunities while another noted that a lack of adequate engagement with pre-class materials (due to external factors) would disincentive attendance). Such in-depth exploration would require extensive follow-up studies with the students in question. This could be accomplished with student focus groups or round-table discussions, where students can discuss their experiences with the flipped classroom in a long-form manner. Such discussions would yield important insight into how this model can be best implemented for future student cohorts.

Within the context of SoTL, our paper provides a public document of reflections and student responses to a multi-year evolution of a renal physiology module. Such public dissemination, open to critique and observation by peers is essential for properly scholarly contributions to SoTL (11, 40, 41, 68). Our work describes how we attempted to design our module around TfU principles, by enhancing active learning opportunities and using feedback from students to contribute to the evolution of the module, thus providing a student centered approach to teaching, a key element of good SoTL practice as described by Felten (28). Furthermore, by allowing students to focus on collaboration with peers and practice problem solving skills in the flipped classroom, our teaching brought students closer to the practice of their future profession where they will be tasked with critically thinking about complex problems daily. Thus, the evolution of the module has brought our teaching style closer to perhaps a signature pedagogy for medical school students, where they are taught to practice skills used within their future profession, rather than rote learning of material (67). It is hoped that our re-design of the renal physiology module as described in this paper, might contribute to a wider discussion with peers on how the use of flipped classrooms and active learning may benefit students in the post-pandemic world.

ETHICAL APPROVAL

All procedures were approved by the Office of Medical Education at the University of Nevada, Reno School of Medicine,.

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