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The Role of Flipped Learning in Managing the Cognitive Load of a Threshold Concept in Physiology

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Abstract

To help students master challenging, threshold concepts in physiology, I used the flipped learning model in a human anatomy and physiology course with very encouraging results in terms of student motivation, preparedness, engagement, and performance. The flipped learning model was enhanced by pre-training and formative assessments that provided opportunities for retrieval practice. Students in flipped learning sections had much higher retention and pass rates than those in non-flipped learning sections. Students also achieved preset benchmarks for factual and procedural knowledge while falling slightly short for conceptual knowledge. I found that the flipped learning model effectively addresses the cognitive load involved in learning physiology, which typically has a high cognitive load. By lowering extraneous cognitive load via intentional content, managing intrinsic cognitive load via pre-training and retrieval practice, and increasing germane cognitive load via the extended class time reserved for problem solving, the flipped learning model offers a very supportive learning environment with numerous opportunities for self-regulated learning for students struggling to master this threshold concept. In future semesters, the increased available class time afforded by the flipped learning format will be used to emphasize conceptual understanding in the problem sets.

Keywords: Flipped learning, threshold concepts, cognitive load, formative assessment, self-regulated learning, retrieval practice.

Flipped learning is a learner centered strategy in which students are exposed to the fundamentals of a concept *prior* to attending the classroom session. Content is delivered via a learning module that is presented in the form of a video, power point, or some other type of instructional medium. This frees up class time for deeper learning activities that address the understanding and application of this newly learned concept (Bergman & Sams, 2012). In this way, the flipped learning model lends itself very well for the scaffolding of a difficult concept, thereby providing learning structure and precluding the learner from becoming overwhelmed by complexities (Tawfik & Lilly, 2015).

Cardiovascular physiology, which deals with the workings of the heart and blood vessels is conceptually difficult for students because of its highly integrative nature. The learner has to juggle several different disciplines such as physics, chemistry, and biology and varying levels of organization such as molecules, cells, tissues, organs, and organ systems

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at the same time (Michael et al., 2002). Any meaningful learning of this topic would require the learner to think like an expert and apply these concepts to clinical problems (Michael, 2001). For these reasons, cardiovascular physiology can be considered to be a *threshold concept*.

A threshold concept is defined as a challenging concept that can be troublesome, transformational, and integrative to the learner (Meyer & Land, 2003). The concept is troublesome because it is conceptually difficult, alien, or tacit (Meyer, Land, & Baillie, 2010). A threshold concept is transformational when it results in new ways of thinking about something or produces a paradigm shift in thinking for the learner. Cardiovascular physiology can be transformational for the learner when hidden connections between lifestyle and cardiovascular function become revealed. It is integrative in the sense that it exposes the interrelatedness of this concept to other disciplines (Meyer & Land, 2003).

A learner that is in the process of mastering the threshold concept is said be undergoing a *threshold experience,* which occurs within a *liminal space* or learning environment. A learner who is yet to begin engaging with the threshold concept is said to be in a *pre-liminal state*; when the learner begins to engage with the concept, the learner is said to have entered the *liminal state*; and once the learner has mastered the concept, he or she is said to have crossed the threshold and reached a *post-liminal* state. Frequently, when faced with a threshold concept, the learner is disinclined to leave the pre-liminal state and pretends to engage with the concept by memorizing bits of seemingly important information without any meaningful learning taking place. The initial challenge for the instructor therefore would be to encourage these students to enter the liminal state so they may begin to truly engage with the concept. This is where the flipped learning method can be extremely valuable. Once the student has been exposed to the background information needed to understand the concept outside of class, regular low stakes quizzes on this material can help build student confidence, interest, and motivation (Warnock, 2004) thereby urging the student to enter the liminal state and engage deeply with the threshold concept. Regular, low stakes, formative assessments providing immediate feedback, have also been shown to have a profoundly positive effect on self-regulated learning (Sadler, 1998; Pintrich & Zusho, 2002; Nicol & MacFarlane-Dick, 2006). When combined with thoughtful scaffolding and frequent low stakes quizzes, flipped learning can help to break down barriers such as lack of confidence and a tendency to procrastinate when faced with a challenging task, both of which prevent the learner from entering the liminal state.

A concept with a high level of difficulty is said to have a high *intrinsic cognitive load*, which is characterized by too many elements within the concept that must interact continuously, requiring a great deal of mental effort. (Sweller, 1994). Intrinsic cognitive load cannot be reduced because the nature of the information is inherently difficult. But it can be managed or manipulated by thoughtful scaffolding (Mayer, 2005). Students learning cardiovascular physiology need to juggle several interacting mini-concepts drawn from physics, chemistry, and biology before gaining conceptual understanding. And this takes a lot of mental effort. In order to understand the concept, students must engage in *intrinsic cognitive processing*, which is limited by the number of interacting elements that can be held in the working memory of the learner (Mayer, 2005). Our working memory can only hold about four units of newly acquired information for a period of 30 seconds (Cowan, 2001). However, these limits can be expanded infinitely when previously learned information stored in long term memory is retrieved (Ericsson & Kintsch, 1995) and enhances working memory. This greatly reduces the mental effort required to grasp a concept. Here is where the flipped learning model makes its strongest contribution. In the non-flipped learning model, the instructor presents all the interacting elements embedded in a concept and the students are expected to juggle a relatively high number of yet unfamiliar conceptual elements in order to comprehend the information. The intrinsic cognitive load is especially evident in this setting and the student struggles to understand the unfamiliar concept. The flipped learning model on the other hand, provides the learner with the opportunity to process new information outside of class, rehearse it, and store it in long term memory before coming to class. Later when faced with the same concept in class, the learner is able to retrieve information from long term memory, thereby vastly expanding the limits of the working memory. This kind of pre-training helps to significantly reduce the mental effort needed for information processing thereby successfully managing the intrinsic cognitive load (Musallam, 2010). When pre-training is combined with retrieval practice as in a short quiz based on the material learned, the effect on learning and long-term retention can be significant (Karpicke, 2012; Roediger & Butler, 2011; Roediger & Pyc, 2012).

We know that learning has taken place when the student is able to transfer newly acquired conceptual knowledge to real world examples. This involves *germane load processing*, which is a kind of deep conceptual processing that alters the very *schema* or mental organization of information in the learner's mind (DeLeeuw & Mayer, 2008). We want to increase the level of germane load processing or *germane cognitive load* in our learners. Another major strength of the flipped classroom is that it frees up class time for deeper learning (Bergman & Sams, 2012). Once in the liminal space, the learner has the opportunity to deepen conceptual understanding and expand procedural knowledge by applying newly learned concepts to novel situations, thereby increasing germane cognitive load.

Alternatively, it is possible to increase a different kind of cognitive load and actually hamper a student's learning by including facts that are not directly relevant to the concept that is being learned. This is called *extraneous cognitive load* (Sweller, 1994) and is described as any kind of mental processing that does not support the learning objective. This can be avoided by evaluating instructional content for inclusion of only the facts and background knowledge that are relevant to the concept. This practice is known as *intentional content* as opposed to the practice of merely *covering the content*. Evaluating content and streamlining it in a meaningful way is a necessary prerequisite to ensure the success of flipped learning (Hamdan McKnight, McKnight, & Arfstrom, 2013) or to ensure any meaningful learning for that matter (Lujan & DiCarlo, 2005).

Here, I describe the adoption of the flipped learning method to accomplish the following: a) to promote student preparedness, motivation, confidence and encourage self-regulated learning; c) to draw students into the liminal space and encourage them to master the threshold concepts embedded in cardiovascular physiology; d) to manage intrinsic cognitive load, increase germane cognitive load, and reduce extraneous cognitive load during this learning process; e) to continually inform and shape my teaching.

Methods

I studied the usefulness of the flipped learning approach for a period of four consecutive semesters in a Human Anatomy & Physiology course each with a class size of 18-24 and a total of 90 students at Bronx Community College, a campus belonging to the City University of New York. Here, I report the effectiveness of the flipped learning method in the lecture portion of the course, and for the topic of cardiovascular physiology, in particular. As a comparison of general student performance, I present data from four consecutive semesters prior to the flipped learning approach. These lecture class sizes were also between 18-24 students with a total of 92 students.

Intentional Content and Formative Assessment

The first step in this process was to evaluate the course content and outline student learning outcomes for each topic based on the philosophy of intentional content usage rather than content coverage (Lujan & DiCarlo, 2006; Hamdan et al., 2013). Learning outcomes were classified into three categories – factual knowledge, conceptual knowledge, and procedural knowledge (Anderson & Krathwohl, 2000). In this way, it was easy to separate the factual knowledge from the other two types and present it in a learning module to be mastered by the students prior to attending class (see Table 1).

Table 1. An excerpt of Student Learning Outcomes and how they are classified.

Student Learning Outcome	Factual knowledge	Conceptual Knowledge	Procedural Knowledge
List the factors that affect stroke volume and explain how each affects stroke volume	X		
Write the full equation for cardiac output	X		
Predict what would happen to cardiac output when stroke volume increases (or decreases) or when heart rate increases (or decreases)		X	
Apply the relationship between cardiac output, heart rate, and stroke volume to a real life situation when a person's cardiac output must increase during exercise to meet the body's increased oxygen demands.			X

Learning modules were designed in a way that it would take the student no more than two hours to master. They were made available in a folder titled "Help for Pre-lecture Quizzes" and contained a total of 10 learning modules (one for each quiz) via the Blackboard learning management system. A weekly lecture quiz served as the primary motivator for students to master this knowledge prior to attending a lecture on the same topic (see Table 4 for a list of topics). These quizzes worth 20 points each, were typically easy and assessed mastery of fundamental knowledge, without which the student cannot hope to achieve deeper conceptual understanding (see Table 2).

Table 2: Examples of Questions appearing on a Low Stakes Lecture Quiz.

I. Fill in the blanks:

1. There is more Na^+ _____________ (inside/outside) cells
2. There is more Ca^{++} _____________ (inside/outside) cells
3. There is less K^+ ______________ (inside/outside) cells
4. When the concentration gradient decreases, the speed of diffusion ___________ (increases/decreases).
5. ____ (simple diffusion/active transport/ osmosis/facilitated diffusion) is the movement of molecules up or against their concentration gradient.
6. When the voltage rises above the resting membrane potential and approaches zero, we call it ____ (depolarization/repolarization/hyperpolarization)
7. When the voltage falls below the resting membrane potential, we call it ____________________ (depolarization/repolarization/hyperpolarization)
8. When the voltage falls and moves away from zero, we call it ________________________ (depolarization/repolarization/hyperpolarization)
9. When voltage gated K^+ channels open, K^+ _____________ (outflow/inflow) occurs.
10. When voltage gated Ca^{++} channels open, Ca^{++} _____________ (outflow/inflow) occurs.
11. Under parasympathetic stimulation, the SA node will make the heart beat ____________ (faster/slower) than 72 beats.
12. The SA node sends its signal first to the _______________ (AV bundle/Purkinje fibers/AV node/Bundle branches).

The quizzes were administered at the start of each lecture session and so latecomers missing the first 20 minutes of class time were not allowed to take the quiz. Students were also not given opportunities to make up a missed quiz. However, only the top 8 quiz grades were included in the lecture quiz average to allow for unforeseen circumstances. Quiz grades comprised 12% of the total grade for the course with each individual quiz contributing 1.5% to the final course grade. Students were repeatedly informed that they had to score 90% or above in these quizzes in order to be able to do well in the higher stakes lecture examination, which includes questions that are significantly more difficult than those that appear in the weekly quizzes (see Table 3). The benchmark for student performance was set at 80% for the low stakes quiz grade and 70% for the higher stakes lecture grade.

Table 3: Examples of Questions Appearing in High Stakes Lecture Exam.

Examination Question	Assessment of
Mr. Z is recovering from a heart attack. However, he is back in the ICU with fluid accumulation in his lungs. The following are the possible reasons for his condition EXCEPT: a) Right ventricular output exceeds left ventricular output b) The stroke volume on both sides of the heart are equal c) The left ventricle is probably damaged d) Left ventricle pumps less than the right ventricle	Procedural Knowledge
The following statements regarding the electrical activity in a cardiac myocyte are true EXCEPT: a) The slow inflow of calcium ions creates a plateau in the action potential. b) The repolarization phase of the action potential is brought about by the inflow of potassium ions c) The plateau increases the absolute refractory period of the action potential. d) The depolarization phase of the action potential is rapid and caused by the inflow of sodium in a positive feedback cycle	Conceptual Knowledge
Two factors that directly affect blood pressure are: a) diet and exercise b) osmotic and hydrostatic pressures c) flow and peripheral resistance d) peripheral resistance and blood volume	Factual Knowledge

A Typical "Lecture Session" in the Flipped Learning Format

The lecture period is usually about 3 hours with two ten minute breaks included. In my flipped lecture session, these blocks of lecture time are organized in such a way as to include a variety of student-centered activities (Figure 1). The quiz is always administered during the first 25 minutes, followed by a five-minute feedback period when I review the quiz with the students. This is followed by short 8-10-minute mini-lectures of new concepts interspersed by periods of rehearsing of conceptual information via interactive note-taking, explanation of worked examples followed by problem solving either individually or in small groups, and breakdown of clinical problem solving into discrete steps (Figure 1). When students solve clinical problems there is plenty of opportunity for peer to peer and instructor to peer interaction. The latter is intended to help students correct any misconceptions and keep them moving in the right track. After working on the problem, students are often invited to the board to breakdown clinical problems into discrete steps using flow charts.

Figure 1. Major elements within a three-hour flipped lecture session.

Formative and Summative Assessments

Formative and summative assessments of student performance were regularly conducted. Formative assessments were made based on the students' performance on weekly quizzes and in-class problem solving exercises. Summative assessments were based on the students' performance on three full length lecture examinations. Student perceptions of the flipped learning approach were collected in the form of responses to a short survey at the end of the first lecture examination. Summative assessment of factual, conceptual, and procedural knowledge of cardiovascular physiology was done using the full length lecture examination as the assessment tool with roughly one third of the questions devoted to assessing each type of knowledge – factual, conceptual, and procedural.

Results

A General comparison of students who were taught using the non-flipped learning method (n = 92) versus the students that were taught using the flipped learning method (n=90) was made. Student performance data from a total of 8 different sections was analyzed with four of these sections from non-flipped learning sections that I had taught prior to the four flipped learning sections. Analysis of student performance data shows that the students in the flipped learning sections did significantly better in terms of pass rates, retention rates, and overall performance (Figure 2).

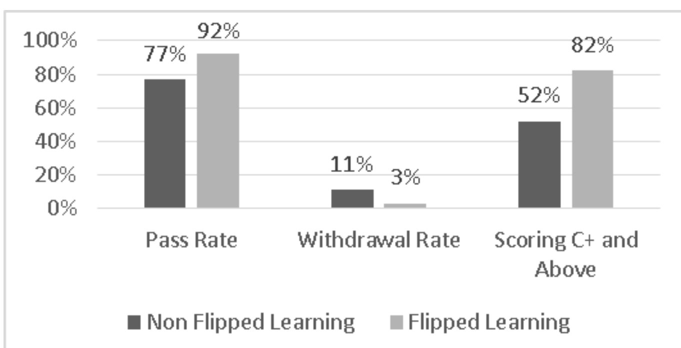

Figure 2. Comparison of overall student performance in non-flipped vs. flipped learning sections.

Analysis of student performance in the high stakes lecture examinations also showed that students from the flipped learning classes performed significantly better with more number of students scoring at least 70% on a given lecture examination (Figure 3). It is important to note that both learning modes operated from the same set of learning outcomes with student centered learning strategies embedded in both. The difference was that in the flipped learning model, students were given the opportunity for pre-training followed by retrieval practice and more class time was devoted to student centered learning activities.

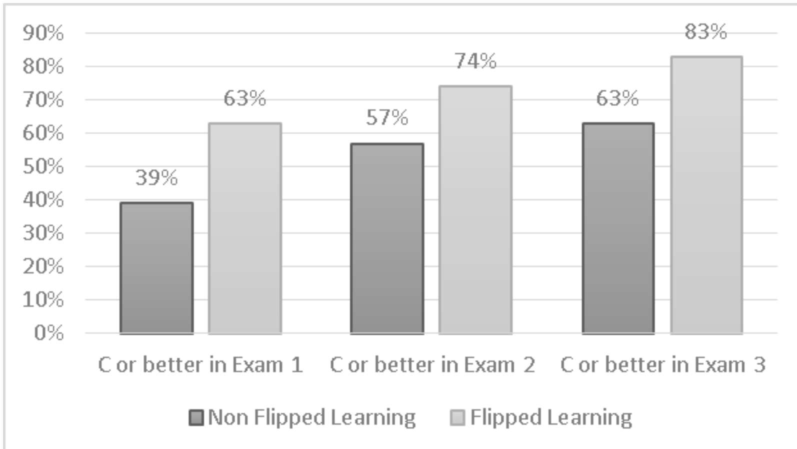

Figure 3. Students scoring at least a C in lecture examinations in non-flipped vs. flipped learning.

In the flipped learning sections designated I, II, III, and IV student performance in the weekly lecture quizzes shows that at least 90% of the students scored 80% or more. There was more variation in student performance across the four sections (60-92%) when students scoring 90% or more on these weekly quizzes was taken into account (Figure 4).

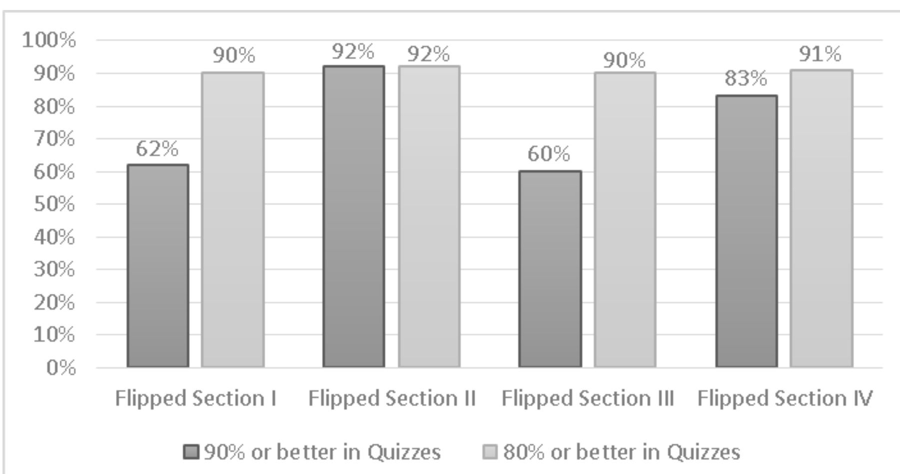

Figure 4. Student performance on weekly quizzes within the flipped learning format.

Students in all four flipped learning sections were asked how they felt about preparing and taking weekly lecture quizzes. 100% of the responses were resoundingly positive. Most of them remarked that it motivated them to keep up with the lecture material or they wouldn't study for the lecture portion of the course until it was time to prepare for a lecture examination.

I used Flipped Section III, which had the lowest percentage of students scoring 90% or above in the weekly quizzes for a closer look at student participation in the flipped learning format, performance in the in-class clinical problem solving in cardiovascular physiology, and performance in the factual, conceptual, and procedural knowledge questions pertaining to cardiovascular physiology on the lecture examination.

A look at student participation data in the weekly quizzes gives us an idea of student motivation to take these quizzes seriously and show up to class on time. Students were allowed to drop two of their lowest quiz grades or miss two quizzes due to lateness or unavoidable absence. Student participation data in the 10 weekly in class quizzes shows that 75% of the students attempted at least 90% of the quizzes with 65% attempting 9 out of 10 quizzes, 10% attempting all 10 quizzes, and the remaining 25% attempting 80% of the quizzes (Figure 5).

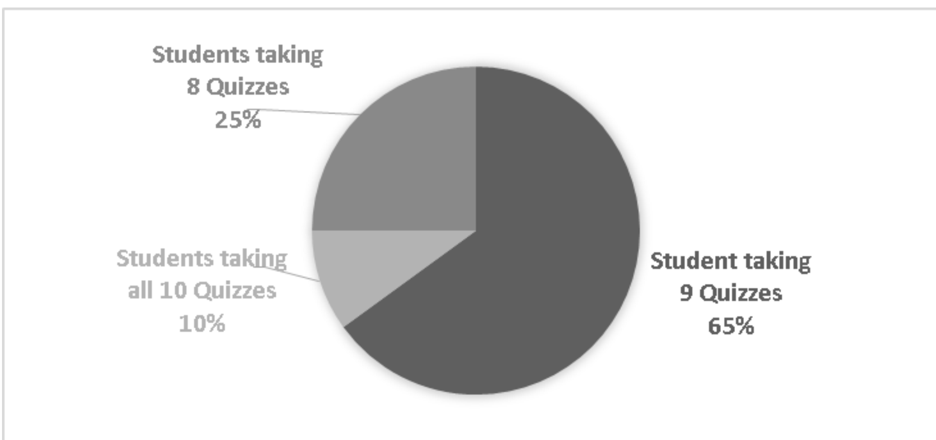

Figure 5. Student Participation in the 10 weekly quizzes within the flipped learning format.

A look at the average quiz grades for each week gives us an idea of student readiness or preparedness for that day's lecture. Student readiness is indicated by the average quiz grades for each week, which was at or above the benchmark of 80% (Table 4).

A look at the time allotted to various in-class activities shows that pre-training opened up more face-to-face class time to address deeper conceptual understanding and germane load processing in the form of clinical problem solving. In the non-flipped learning format, factual knowledge was presented in class thereby limiting the time available for

Table 4. Cardiovascular Physiology is addressed in the first four flipped learning modules.

Lecture Quizzes	Flipped Learning Modules that address Factual and basic conceptual knowledge	Average Quiz Grade
1	Electrophysiology of the Heart	84.25%
2	Electrophysiology of the Heart and Pressure Gradients	81.97%
3	Hemodynamics	80.38%
4	Hemodynamics & Capillary Exchange	90.13%
5	Osmolarity, Viscosity & Erythropoiesis	93.82%
6	Lymphatic Pathway and Nonspecific Defenses	85.27%
7	Antibody mediated immunity	91.11%
8	Physiological Pathway of Air & Breathing Mechanics	85.74%
9	Pathway of Urine Formation	87.21%
10	Digestive Pathway and Chemical Digestion	88.53%

students to participate in small group or individual clinical problem solving, receive immediate feedback, and correct misconceptions. Whereas, in the flipped learning format, 30% more class time was devoted to formative assessment and feedback (Figure 6).

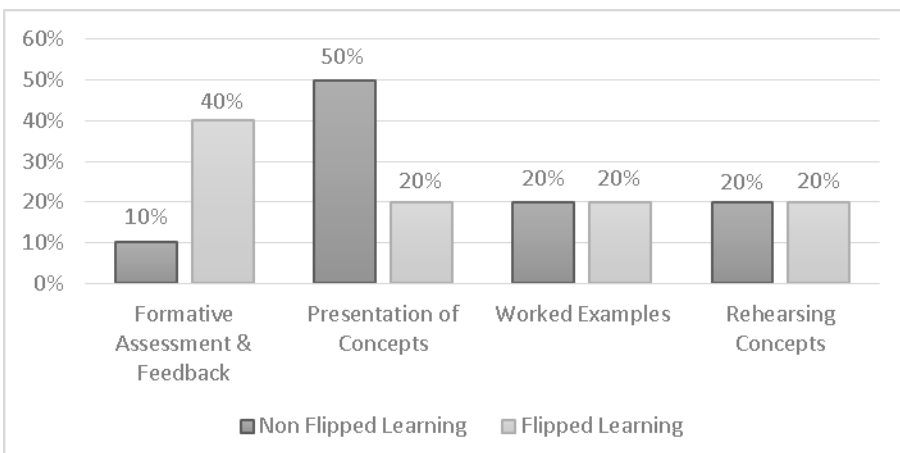

Figure 6. Percentage of class time spent on various learning activities.

Cardiovascular physiology was taught in four lecture sessions and the students addressed a total of 16 novel clinical situations (Table 5). All of the clinical problems presented to the students were preceded by a worked example, that was used to demonstrate “how to think like a physiologist” via a flow chart that breaks down a clinical problem into discrete steps. More than 80% of the students were successful in arriving at the correct answer when addressing these clinical problems. However, there was a tendency to obscure explanations by including elements not directly pertinent to the problem. Even when

Table 5: Formative Assessment and Feedback of Clinical Problem Solving in Cardiovascular Physiology.

Concept	Clinical Problems Outlined	Formative Assessment & Feedback
Electrophysiology	1. How does a Ca++ channel blocker help to lower the heart rate? 2. How do Beta Blockers help to lower heart rate?	94% of the students were able to solve the problem with some feedback. 80% of the students were able to solve the problem with some help.
Venous Return	Explain how each of the following situations affects venous return? 3. Broken rib 4. Deep breathing 5. Sitting for long periods 6. Increased Atrial Pressure 7. Standing Upside down 8. Lying down with feet raised higher than the heart	Students were able to answer all of these correctly except for #6. Only 50% were able to connect high arterial pressure with lowered venous return.
Blood Pressure	9. How does arteriosclerosis result in high blood pressure? How does a stent help to lower blood pressure?	They were all able to answer this correctly. However, only 33% were able to complete the flow chart without bringing in unnecessary elements such as viscosity.
	How do each of these factors affect Blood Pressure? 10. Weight gain 11. Atrial Natriuretic Peptide 12. Profuse sweating 13. Anti-diuretic hormone 14. Diuretic 15. Tumor in the adrenal medulla increasing epinephrine production	90% of the students arrived at the correct answers but there was a strong tendency to bring in unrelated elements into their flow charts. Only 10% of the students were able to make the connection between adrenal medulla, overproduction of epinephrine and high blood pressure.
Stroke Volume	16. Why does a person who has recently suffered a heart attack sometimes suffer pulmonary edema?	100% of the students were able to answer this correctly but were not able to construct a flow chart by themselves.

students were able to construct their own flow charts correctly they stated that they did not feel confident in their ability to do this on their own.

The full length high stakes lecture examinations were used as summative assessments, which assessed student outcomes for factual, conceptual, and procedural knowledge. The first lecture examination assessed student understanding of cardiovascular physiology and their ability to apply this knowledge to solve clinical problems. Results of this assessment showed that students achieved the pre-set benchmark of 70% for factual and procedural knowledge but fell slightly short of the benchmark for conceptual knowledge (Figure 7).

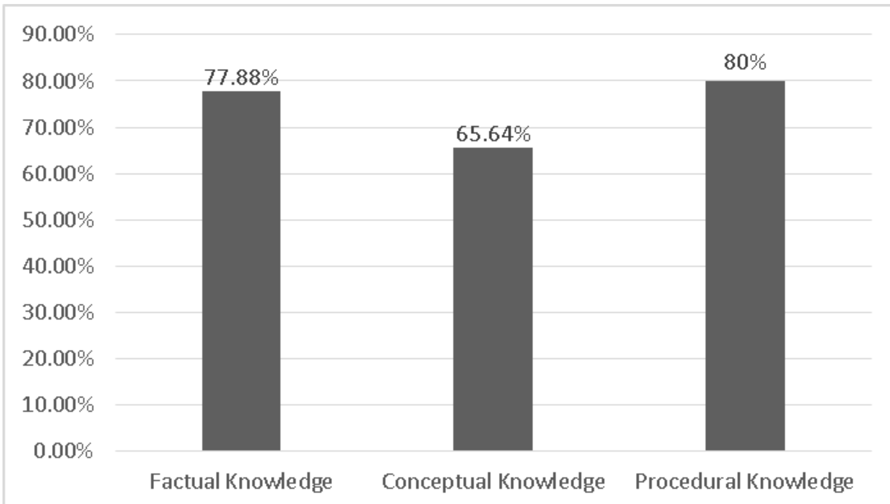

Figure 7. Percentage of students answering questions correctly in the three knowledge areas.

The lecture examination also included one clinical problem solving question in the form of a short answer. About 83% of the students answered the question correctly overall. Among those that answered the question correctly, 40% made one or two mistakes by including unrelated elements in their flow charts.

Discussion

Practical implications of this study

The flipped learning approach has a direct positive impact on student motivation, participation, preparedness, confidence, and performance. For the instructor, the flipped learning approach can save time that can be used for deeper conceptual understanding and application.

1. Overall, the lowered withdrawal rates, increased pass rates and increased rate of students scoring C+ and above in the flipped learning sections in comparison with

the non-flipped learning sections (see Figure 2) is an indication that the flipped learning approach can have a strong influence on student motivation to successfully complete a challenging science course.

2. Even in the lowest performing flipped learning section there was strong student participation in the weekly quizzes (see Figure 5). When asked if the weekly quizzes were helpful, student response was overwhelmingly positive. They stated that the quizzes motivated them to keep up with the lecture material and to help prepare for lecture examinations. The flipped learning approach combined with retrieval practice can boost student participation.
3. With more than 90% of the students scoring 80% or more on the weekly quizzes, class preparedness was high. This also increased student confidence and engagement during the lecture session.
4. In all three exams students in the flipped learning sections did significantly better than those in the non-flipped learning sections (see Figure 3). The flipped learning approach when combined with retrieval practice can greatly improve student performance in the long run.
5. For the instructor, flipping one third of the lecture and following the philosophy of intentional content can free up valuable class time for deeper learning (see Figure 6).

Theoretical implications of this study

The flipped learning approach when applied efficiently can harness the power of formative assessments and retrieval practice to enhance self-regulated learning. It can lower extrinsic cognitive load by the practice of intentional content; manage intrinsic cognitive load by pre-training and interactive note-taking; and raise germane cognitive load by the use of worked examples.

1. Formative assessments can confer affective, cognitive, and behavioral benefits on students by giving them a goal to which they can aspire, build self-esteem by learning from mistakes, boost confidence, and positively influence study behavior by promoting self-regulated learning (Sadler, 1998; Nicol & MacFarlane-Dick, 2006; Black & Wiliam, 1998). I have found that by reminding students to score 80% or above weekly quizzes, giving them a weekly opportunity to learn from their mistakes, feel good about their performance, and track their own progress, it is possible to reap the benefits of formative assessment. This is a kind of self-assessment that is known to enhance future performance in summative assessments such as the full length or final examinations (McDonald & Boud, 2003), which I have also seen from my results (see Figure 3).
2. Pre-training (Musallam, 2010) and retrieval practice (Roediger & Butler, 2011; Roediger & Pyc, 2012; Karpicke, 2012) can help to manage intrinsic cognitive load. By practicing intentional content rather than merely covering the content, it is possible to lower extrinsic cognitive load (Lujan & DiCarlo, 2006; DeLeeuw & Mayer, 2008). If both of these cognitive loads are properly managed, it is possible to increase germane cognitive load, a type of processing that allows the student to apply conceptual knowledge to novel situations. During the four lecture

sessions on cardiovascular physiology the students addressed a total of 16 novel clinical situations (see Table 5) and students were largely successful with more than 80% of the students solving the problems correctly, thereby demonstrating germane cognitive processing.

3. Meaningful learning takes time and this journey can be troublesome. (Lujan & DiCarlo, 2005). Viewing this learning process as a threshold experience allows us to focus on the struggle that the students face to master difficult concepts. The flipped learning model has helped immensely in drawing students from the pre-liminal state to the liminal state to engage deeply with this threshold concept in physiology. The threshold experience reveals the non-linear learning process in that we see students brimming with confidence as they do well on the quizzes and then struggle with the mastery of conceptual understanding. Yet they demonstrate the ability to apply this knowledge to real world situations. At the same time, they oscillate towards a loss of confidence in their abilities and end up including unrelated elements in their explanations. This is a classic characteristic of the threshold experience. The learner attempts bold *excursive journeys* into the conceptual landscape towards better understanding interspersed with *recursive journeys* into areas of confusion and loss of confidence (Cousin, 2006). An instructor who is aware of this struggle can provide a supportive learning environment or *liminal space* that addresses these excursive and recursive journeys (Land Cousin, Meyer, & Davies, 2005).

Overall, I have found that the flipped learning model provides a highly supportive and effective learning or *liminal* environment for the student. By taking into consideration the functioning of our working and long term memory, the flipped learning strategy appears to be highly compatible with the human cognitive architecture (Kirschner, Sweller, & Clark, 2006).

In future semesters, I will alter the design of the classroom activities to include formative assessments to test conceptual understanding and step up opportunities for self-assessment both inside and out of the classroom. I would also be interested in further exploring the relationship between the flipped learning approach and the development and maintenance of self-regulated learning.

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