Improvements on the Peer-Instruction Method: A Case Study in Multivariable Calculus

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Abstract

One of the challenges faced by instructors implementing a flipped classroom is the students' resistance to embrace the method. Many factors can contribute to this outcome: students may be initially skeptical of the method due to its novelty, they may feel like it requires too much discipline to keep up, or they might also perceive it as giving them a greater workload than a more traditional approach. In order to address this, strategies were designed and tested in a multivariable calculus course. The structure employed was inspired by the peer-instruction method, which requires students to watch educational videos or do readings prior to class and then to discuss with their peers to solve conceptual problems in the classroom. However, the main variation proposed is that the videos were produced at two different paces for them to choose from: one consisting of a traditional lecture speed where the instructor writes as he speaks, the other consisting of a shorter version where the instructor comments on prewritten text and figures. The appreciation and effectiveness of this choice in videos was measured with surveys, and the results are positive. In addition, a comparison is established with previous iterations of this course which were taught using a traditional lecture-based approach. It is found that students felt more engaged and that they did not perceive an increase in workload. Suggestions to improve the presentation of the flow of in-class questions are also presented.

The flipped classroom is a modern and powerful way to improve student engagement inside and outside the classroom [1, 17]. The goal of the method is to move the traditional lectures outside of class-time in order to focus on hands-on activities while the instructor is present with the students. Many variations have been proposed depending on the level and field of study of the course, but one popular approach in sciences is the Mazur peer-instruction method [2, 3, 11, 7]. In this method, students have to view educational videos or do readings related to the material for their homework assignment before coming to class. Then, while in class, students solve a series of conceptual problems individually and/or by discussing with their immediate neighbors. The specific procedure is referred to as a ConcepTest. The flow of questions is typically altered by the instructor according to the answers provided by students in order to focus on what they are actually struggling with.

This method offers a number of advantages for the students' experience, the greatest one arguably being its ability to drastically increase engagement during class-time for courses with larger enrollment. However, as it has been reported in the past [2], instructors using it may face several challenges which could potentially lead to its rejection by some students. First, because most students are still being taught science with traditional lecture-based approaches, they might be initially skeptical of this new technique; the "didactic contract" has to be renegotiated [4, 15]. Also, just as in most flipped classroom implementations, it requires the students to be disciplined in order to complete the required assignments prior to each flipped session. Even though the amount of work actually expected of them does not vary, this might lead to an increase in the workload perceived by students [8]. In other words, the amount of work students feel they have to put in the course to succeed might be higher than the amount of work they believe necessary to keep up and achieve the same outcome in a regular course.

Ways to dampen these difficulties using tests on the assigned work in class, for example with small quizzes, or outside of class with web-based tests, have been used [2, 7]. While these techniques can effectively deal with the personal discipline issues, they most likely don't reduce the perceived workload. One of the goals of the experiment reported in this paper was to explore the effect of giving students choices for their assignments to deal with these problems. More specifically, the proposed strategy was to produce more than one version of the videos with different paces and lengths. The same content is delivered and only the format changed. The logic is twofold. One: some studies reported that shorter videos (preferably under 6 minutes) were better for audience retention in online courses [6]. On the other hand, some studies suggest the attention span of students in lectures does not necessarily decline after 10 to 15 minutes and that individual differences should be accounted for [18] Two: research indicates that when given choices for their assignments, students are likely to be more motivated and complete their homework [5, 16].

The Mazur peer-instruction method was implemented with this new video strategy in a second-year multivariable calculus course. For this course, a partial flip was used: 70% of the sessions used a flipped approach with the Mazur method, while the other 30% consisted of small presentations followed by team problem solving activities. The videos assigned to watch before the flipped classes were created in two different versions: one slower paced version where the instructor writes as he speaks and another shorter version where the instructor reads and comments on prewritten text and figures. Students were free to decide which version to watch as a part of their assignment, and both versions contained the same explanations of concepts. In order to measure the appreciation and effectiveness of these videos with students, a survey was conducted after four weeks of instruction, and a course evaluation questionnaire was filled at the end of the semester.

Another improvement attempt on the method had to do with the presentation of the ConcepTest questions given in class. The importance of asking good conceptual questions has been clearly recognized [2, 13]. However, it is our impression that most implementations of ConcepTest visually present questions with traditional slides where the tree-like structure the instructor goes through is hidden from students. From the students point of view, all that can be seen is a series of questions where one follows the other in a seemingly predetermined order. In the experiment reported here, the ConcepTest questions given in class were visually categorized by topic and organized inside a tree using the flexibility of Prezi [14] for the presentation. Students could therefore see how every problem related to the major ideas and fundamental course concepts. While the effect of this strategy was not directly assessed through the survey and questionnaire, we will share several thoughts and recommendations for future implementation and research on the subject.

This paper is organized as follows: Section 1 gives an overview of the Mazur peer-instruction method. Section 2 follows with details of the current experiment, with information about the videos in 2.1 and comments on the flow of ConcepTest questions in 2.2. Then, Section 3 presents the results of the feedback survey in 3.1 and of the course evaluation questionnaire in 3.2. A brief discussion on the final grades achieved by students as a function of clicker usage is also presented in Section 3.3. Finally, some conclusions are given in Section 4.

1 Overview of the Peer Instruction Method

The Mazur peer instruction method [2, 3, 11] relies on several fundamental ideas. First, the time spent in class should be freed of lecturing. More specifically, a flipped classroom approach is used and before coming to class, students have to do readings or watch videos explaining concepts from the course objectives as a part of their assignment. Then, thanks to the students pre-exposure to the class material, class-time can be devoted to problems and exercises. Second, these in-class problems are designed to build understanding of conceptual questions rather than to focus on computational questions. The target is therefore put on the meaning and understanding of key concepts as opposed to emphasizing the ability to perform routine calculations. Finally, students rely more heavily on their peers to learn those concepts during class. Indeed, discussions with colleagues is at the center of the learning strategy. To better illustrate how this can be implemented, let us look at a possible procedure for a large class. This type of procedure is referred to as a ConcepTest by Mazur and his collaborators.

In-Class Procedure

1. The instructor poses a question (usually a multiple choice question).
2. The students take a few minutes to think about it and work individually.
3. The students use hand-held electronic clickers to submit their answers.
4. Depending on the answers provided, the instructor either
   (a) asks students to turn to their neighbors and to try to convince them of their answer. After a few minutes, students re-submit their electronic responses.
   (b) gives the students a hint and asks them think about it individually or with their neighbors. After a few minutes, students re-submit their electronic responses.
   (c) provides explanations regarding the question at hand and then goes back to step 1 with a different question.
   (d) moves on to the next question starting at step 1 again.

This educational algorithm is then repeated, while the next question selected by the instructor varies with the class comprehension of the concept at hand. This method has become more and more popular in recent years for a variety of reasons. For example, it gives the possibility to engage large numbers of students in discussion where they are all directly involved. The pre-exposure to material increases the comprehension and retention of the lessons learned in class. Also, the focus on conceptual questions has a significant impact on the students basic understanding of fundamental concepts. However, as mentioned earlier, it suffers from difficulties related to student participation.

2 Details of the Experiment

During the flipped sessions, the instructor would begin the session by asking the participants if they had questions concerning the videos. However, no summary of the videos was ever given at the beginning of a session to try to accommodate individuals who failed to complete their pre-assignment. In the non-flipped sessions, the instructor would go over the notes at the beginning of the class, and then the students would attempt to solve problems in teams with their peers. This approach was used to cover portions of the course theory consisting in the resolution of longer and more applied problems such as optimization problems. It also had the effect of reducing the amount of weekly videos required to view before class to avoid overloading students. A similar split between flipped sessions and more traditional sessions has been employed by Mazur [2].

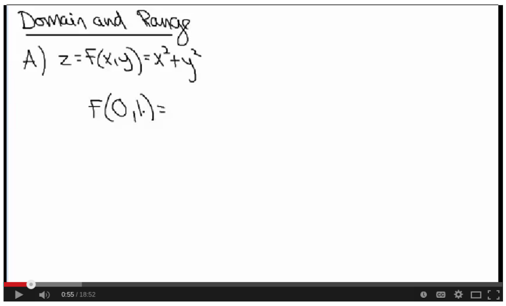
The typical audience for this course consists mainly of students in engineering, mathematics, physics and chemistry. It has an hour long weekly tutorial session where students worked through problems with the help of a teaching assistant. The graded assessment methods consisted of 2 midterm written evaluations, 4 problem sheets to be handed in throughout the term and one final written examination. Students also had additional suggested exercises to work on throughout the term, but while they were strongly encouraged to do them, their completion was not monitored. In addition, a small percentage of the final grade was given as a function of the number of flipped sessions in which students participated with their clickers.

2.1 Videos at Different Paces

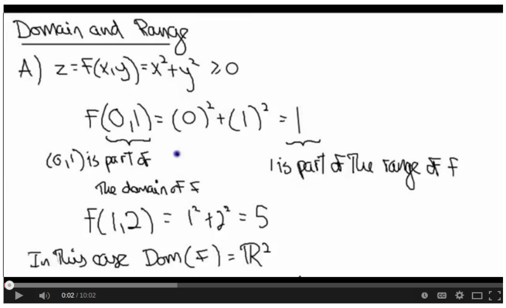
The length and pace of the videos are aspects that might have a crucial impact on the number of students actively watching videos before class. Indeed, on one hand, recent studies [6] about online videos designed for MOOC (Massive Open Online Course) concluded that shorter videos were better, suggesting a maximum of 6 minutes. On the other hand, other studies [18] concerning attention span of students in lectures suggest that some students are able to concentrate for longer periods of time and that individual differences between students should be acknowledged. It might therefore be useful to give students access to more than one format option with different paces and lengths. Also, it has been reported that giving students choices for homework leads to more motivation and better engagement in the course, as well as a higher completion rate for the assignment [16, 5]. This is yet another argument in favor of providing students with multiple video options to choose from.

It is not difficult to imagine that the first thing that comes to mind to any instructor reading such a statement is the potential higher amount of time spent making videos! However, it is possible to create videos at different paces without drastically increasing the instructor's workload. For the specific case of multivariable calculus under consideration in this paper, two different versions of most videos were created. The longer videos consisted of recordings of the instructor lecturing and writing as he spoke in a similar way to a traditional lecture. The user would only see the text and equations on the screen (the instructor could not be seen). This style is the one employed by the Khan Academy [9] in most of their videos. Figures and graphics created with Matlab [12] were also displayed as needed to better demonstrate three-dimensional concepts, for example.

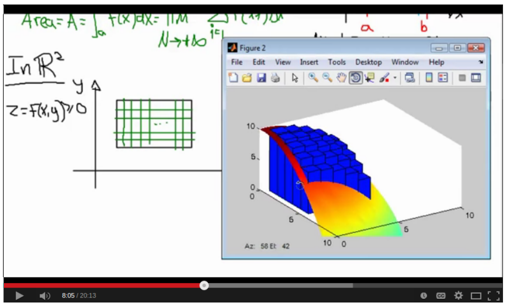
Once a slower paced version of a video was done, all the text written on the screen as well as the figures and graphs were saved. Then, the instructor would create another video by going over the prewritten text, giving more or less the same explanations and displaying the same figures, but



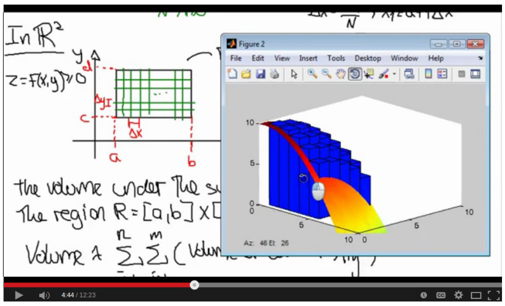
(a) Slower paced version of video 1



(b) Faster paced version of video 1



(c) Slower paced version of video 2



(d) Faster paced version of video 2

Figure 1: Screen capture of the slower and faster paced versions of two videos. For the slower paced video, the instructor writes as he speaks, whereas for the faster paced version, the instructor comments over the same pre-written text.

without adding any new text. This second video was thus considerably shorter than its slower paced counterpart. It was also faster to produce than the other type of video. Indeed, as the planning of the video is already done and since the instructor had already rehearsed by making the longer video, its production time was usually quite short. Figure 1 shows a screen capture of both versions of two such videos created for the experiment presented in this paper.

The videos were distributed on Youtube [19] via the instructor's personal channel. There, playlists were put in place for both types of videos so that students could simply keep watching and the correct video would load immediately after the previous one was over. In addition, a detailed list of the videos required to watch prior to each class was given on the course webpage, with links to the corresponding Youtube pages. Throughout the term this experiment was conducted, students had to watch a total of 44 mandatory videos created by the instructor. Most of these videos were available in two paces. On average, they had to watch 2.93 videos per flipped session, which gave a weekly average of 3.38 videos. They also had access to a total of 18 optional videos which included either reviews from previous courses or additional examples. The slower paced videos lasted 16 minutes and 45 seconds on average, whereas the faster paced videos lasted 10 minutes and 57 seconds on average. The intent was to have an average closer to the prescribed 6 minutes for the shorter videos, as recommended in [6]. This is something that should be more closely monitored during the production phase in the future. However, as it will be shown in Section 3, many students found different video lengths useful, and conclusions are drawn from a survey on the comparison between videos.

2.2 In-Class Flow of Questions

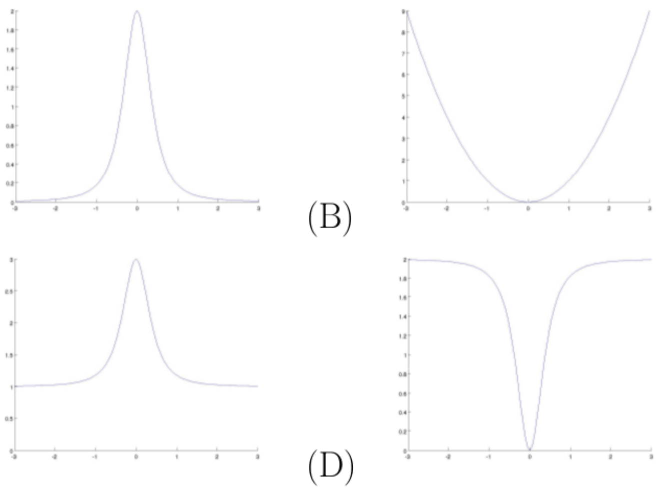
The ConcepTest questions given in class play a central role in Mazur's method. Their goal is to target specific issues regarding fundamental concepts and to challenge the students' understanding of these concepts. They are also used to keep students from falling into well-known traps. Figure 2 displays two examples of questions used in the current experiment. The questions are designed to focus more on the understanding of concepts than the mere computations from formulas. In each case, students have to choose from several potential answers to the question, each of which is either the right answer, or an answer displaying a typical mistake. When going through a ConcepTest, it is sometimes difficult for an instructor to remember exactly which answers correspond to which mistake. As the tally of student answers becomes available, the instructor has to direct the next phase of the procedure according to the class response. The strategy employed to facilitate this decision process was to have details corresponding to each choice written as a comment in the LaTeX file. This file would then be opened on the instructor's computer in front of the classroom. At the same time, the compiled PDF version would be displayed on the screen for the students to see. This process of displaying the right file on the right screen can be made automatic to ease the instructor's work.

The main variation on the ConcepTest questions attempted had to do with the display and flow of the questions. Indeed, it is our impression that most of the time, the questions are presented following one another, in a seemingly linear fashion such as a regular slideshow. Presentation software has considerably evolved in recent years and powerful tools are now available for educators. One such tool is the software Prezi [14], which amongst other features enables the presenter to give its audience an overview of several parts of his presentation at once. This property can be used to visually organize the ConcepTest questions according to several potential categories such as the concept studied, the underlying course objective or even the resolution strategy. In this way, it was hoped students may be able to better identify the course objectives they are struggling with while answering in-class questions. Figure 3 a) and b) present examples of how this visualization strategy was used in the course under study. For example, in Figure 3 a), the broader concepts displayed in the circles are 3D Vectors, Lines and Planes in Space and Curves and Motion in Space. The subconcepts of 3D Vectors displayed in the squared brackets are Distance, Angle and Orientation, and Area and Volume. Figure 3 b) shows the subconcept Angle and Orientation, which itself contains 6 questions and the "subsubconcept" Orthogonality.

This idea of grouping ConcepTest questions to help students remains in an early stage. Even though the categories selected for the experiment had to do more with course concepts, we believe that a grouping by course objective might benefit students even more. It would also be interesting to group the videos as well under the course objectives so that students could go back and rewatch the ones associated with a specific course objective they struggled with during class.

With this presentation structure, students would be aware that the instructor skips some questions and orients the flow of ConcepTests according to their answers. Initially, we intended to only give online access to the questions covered in class. However, after conducting a survey (more details on the survey are given in Section 3) and by popular demand, we made all the questions available on the course webpage as exercises after every session, whether they were covered in class or not (but the answers were not provided). From that point onwards, the fact that students would know that questions were skipped during flipped sessions did not appear to be a source of concern for them anymore.

Which of the following represents the graph of the curvature κ of the curve $y = x^2$ where $x \in [-3, 3]$?



(A) (B)

(C) (D)

(E) None of these

(a) Question 1

Consider the double integral

$$\int\int_R xy^2 \, \mathrm{d}A$$

where R is the region bounded by $y = x^2$ and the line $y = 4$. Set up this integral in the order dydx The answer is

(A) $\int_{-2}^{2} \int_{x^2}^{4} xy^2 \, \mathrm{d}y\mathrm{d}x$

(B) $\int_{0}^{4} \int_{4}^{\sqrt{y}} xy^2 \, \mathrm{d}y\mathrm{d}x$

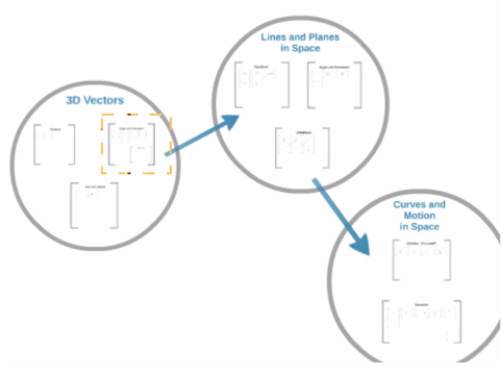
(C) $\int_{0}^{4} \int_{\sqrt{y}}^{4} xy^2 \, \mathrm{d}y\mathrm{d}x$

(D) $\int_{-2}^{2} \int_{4}^{x^2} xy^2 \, \mathrm{d}y\mathrm{d}x$

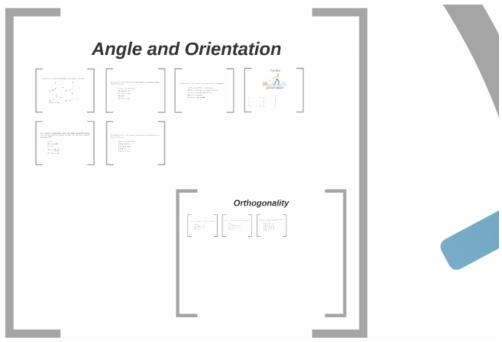
(E) None of these

(b) Question 2

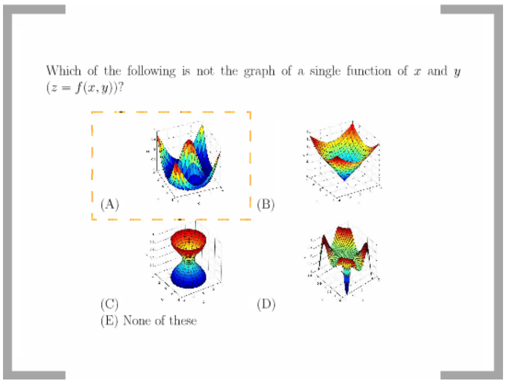
Figure 2: Two examples of ConcepTest questions used in the course.



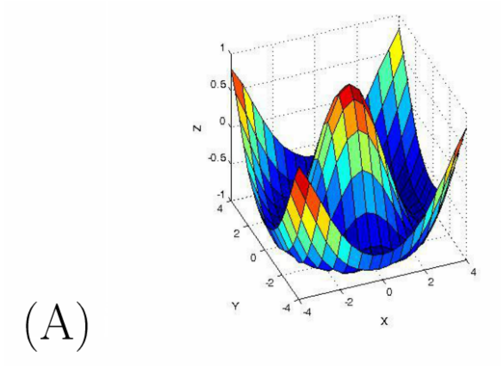
(a) Broad Concepts



(b) Subconcepts



(c) ConcepTest question



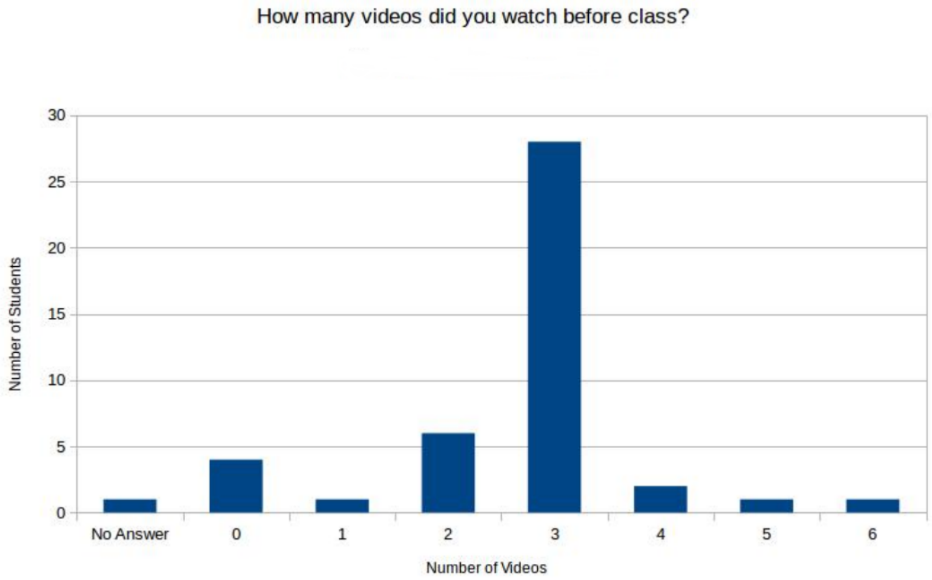
(d) Zoom in on one graph

Figure 3: Figures a) and b) show two examples of ConcepTest questions grouped by concept. The region surrounded by a dashed rectangle in a) corresponds to b). Figures c) and d) display the ability to zoom in in order to better visualize answers in a ConcepTest question. Note that Figure c) is not obtained from zooming in on b): it belongs to a different concept.

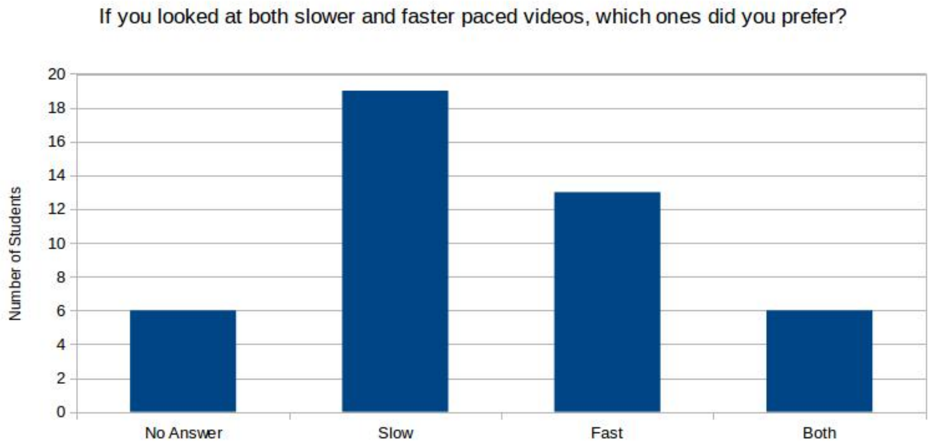
Finally, another trademark aspect of Prezi presentations which can be put to use is the ability to zoom in and out of slides. This can prove especially useful when questions involve graphs or figures, which may contain details harder to visualize from a distance. An example of how this looks like is presented in Figure 3 c) and d).

3 Results of the Experiment

In order to measure the appreciation of this choice of videos and course structure on students, a written anonymous survey was conducted in class at the end of the fourth week of instruction. In addition, at the end of the semester, students had to answer a detailed course evaluation. The corresponding results are given in this section. A discussion of the association between final grades of students and clicker usage is also presented after.



(a) Video Question 1



(b) Video Question 2

Figure 4: Results of two questions concerning videos in the fourth week survey. For that particular session the students were polled, there were two choices of 3 videos two watch: 3 slower paced videos or 3 faster paced videos.

3.1 Fourth Week Survey

The results of two questions regarding videos from the written survey given to students at the end of the fourth week of instruction are presented in Figure 4. The first diagram shows that most students were watching all the required videos, thus keeping up with the method. It is interesting to notice that a few students were watching more than 3 videos, which indicates that they were watching both slower and faster paced versions (there were two choices of 3 videos to watch). Actually, some students commented that they liked to first watch the shorter version to get exposure to the material without taking notes. Then, they would put on the slower version and take detailed notes. The second diagram (4 b)) indicates that there was not a strong student preference for a specific version of the videos. Several students in fact answered that they preferred having access to both, even though this was not necessarily implied as a possible answer from the question.

Open ended questions asking students for their comments were also part of the survey. If similar types of comments are grouped together, we get the following results:

- To the question: "What did you like about the videos?", the three most frequent responses were
  - Possibility to rewind/pause/rewatch lectures (47.7% of students)
  - Clear explanations (18.2% of students)
  - Two paces available (11.4% of students)
- To the question: "What do you think could be improved about the videos?", the three most frequent responses were
  - Give more examples (9.1% of students)
  - Make shorter videos (4.5% of students)
  - Use more colors (4.5% of students)

The possibility to view a lecture at your own pace (and leisure), as pointed out by 47.7% of students, is a well-known advantage of the flipped classroom. It is interesting however to observe that the third most popular comment had to do with the two different paces available, again pointing out to the fact that this availability is having an effect on student participation.

Finally, some questions concerning the peer-instruction sessions with clickers ended the survey. Presented below are the three most common responses:

- To the question: "What do you like about the clicker sessions?", the three most frequent responses were
  - Solve many more problems than in a regular math class (22.7% of students)
  - Instant feedback (18.2% of students)
  - Gives more opportunity to think about the material (11.4% of students)
- To the question: "What do you think could be improved about those sessions?", the three most frequent responses were
  - Give access to questions online (11.4% of students)
  - Give more explanations (9.1% of students)
  - Give more/less time to answer questions (9.1% of students)

The positive comments given by the students to the first question are more a testimony to the peer-instruction method than an analysis of the added benefits of the proposed variation with concept grouping. Indeed, since students were new to the peer-instruction method and since they were not specifically polled concerning the usefulness of grouping of questions in categories, few conclusions can be drawn concerning this variation. A few students nonetheless shared positive thoughts concerning the presentation of the ConcepTest questions. This should be taken as additional motivation to conduct more research on the subject. Also, as previously stated, questions were given online after this survey was conducted to address the principal suggested improvement from students.

3.2 Course Evaluation

A course evaluation questionnaire was filled in class by students at the end of the semester. For the term in which this flipped experiment was put in place, the questionnaire used was actually the same as the one in two previous iterations of the same course taught by the same instructor with a traditional lecture-based approach. We may thus compare some of the responses, for example to questions related to workload and engagement.

The results of some general questions regarding the course are given in Table 1. For all three questions, there is an increase in the students appreciation of the corresponding aspects of the course. To see if this increase is statistically significant, we computed the p-values given by a two-tailed Mann-Whitney U test between the groups of students taught with lecturing and the group of students enrolled in the flipped version of the course. As we see in the table, the null hypothesis can only be rejected at reasonable significance levels for the question on opportunities to engage with the course material. However, it is worth pointing out that the sample size for the flipped iteration was relatively small (38 respondents out of 52 students enrolled) as opposed to the one for the traditional lecture (77 respondents out of 102 students enrolled). It would be worth repeating this experiment with more students to potentially achieve statistical significance, especially since we used a more stringent two-tailed test for the analysis (as opposed to a one-tailed test). The effect of the peer-instruction method can nonetheless be observed: students felt significantly more engaged with the course. They also possibly better appreciated the homework (now with videos) and believed the course offered a better learning experience, but these two claims remain anecdotal for now.

All these results can very well be a direct consequence of Mazur's model. Since one of the goals of this study was to increase student participation in the method, it is worth measuring aspects related to reasons why students fail to embrace the method. One major problem instructors face when introducing the flipped classroom to students is the perceived added workload of the method, especially when they are unaccustomed to it. While it is true that students have to be more disciplined in terms of completing the assigned work prior to class-time, the real total workload expected of them does not typically differ from a regular lecture-based course. This was the case in the current experiment: the workload was designed to be roughly equivalent to the lecture-based previous iterations of the course. More specifically, students had 1 less written assignment to hand-in and the remaining 4 written assignments were shorter than for the previous iterations, but everything else was the same. However, when faced with the weekly task of viewing videos, students might feel like they are working harder than usual. In order to observe whether the measures put in place had any effect in the current implementation of the peer-instruction method, Figure 5 gives the students' answers in the course evaluation for two questions related to workload. We see that there is no major difference

Question	Results for traditional lecturing	Results for flipped experiment	p values
“The assigned work helped your understanding of the course content”	4.17	4.45	0.1238
“Course provided opportunities to engage with the course material”	3.77	4.26	0.0083
“Overall, the course offered an effective learning experience”	4.23	4.45	0.2478

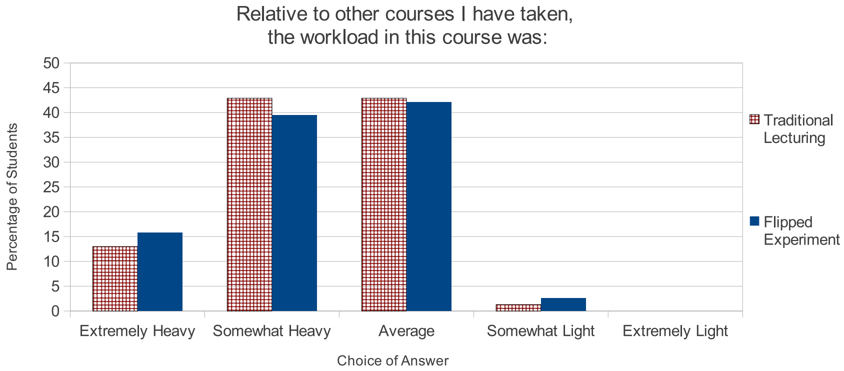
Table 1: Course Experience: Results of questions answered by the students in the course evaluations on a scale of 1 to 5 (1=very poor, 5=excellent). The results for traditional lecturing are the averages of students responses from the two previous iterations of the same course taught by the same instructor, but with a traditional lecture-based approach. The p-values are the ones given by a two-tailed Mann-Whitney U test.

with the previous iterations taught with traditional lecturing. It is thus fair to say that students did not believe they were putting more work into the course. This normalization of workload might also have contributed to the success of the experiment in terms of students embracing the method.

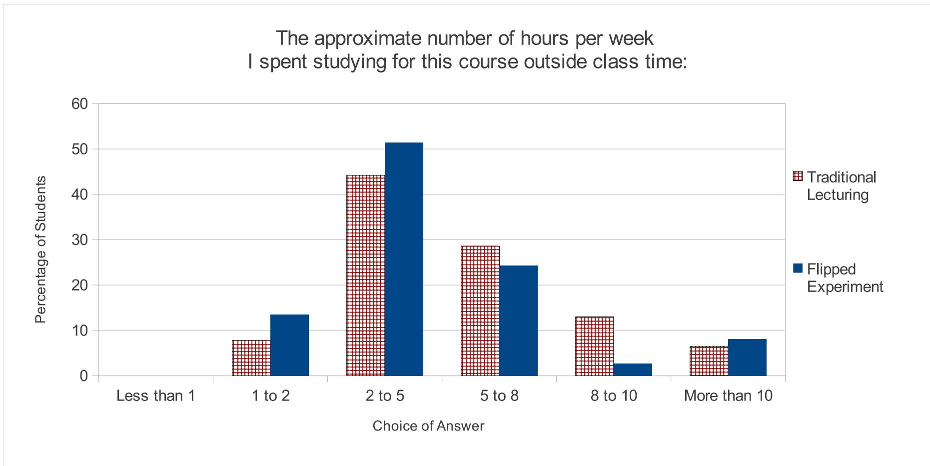
Some open-ended questions that were part of the course evaluation questionnaire are relevant to the analysis conducted here. It is especially interesting to report the ones concerning the overall strengths and weaknesses of the course, as it is given below:

- To the question: “What are the main strengths of this course? ”, the five most frequent responses were
  - Videos (39.5% of students)
  - Clear explanations (31.6% of students)
  - Flipped Classroom (15.8% of students)
  - Multitude of examples solved in class (13.2% of students)
  - Variety of help tools (10.5% of students)
- To the question: “How could this course be improved? ”, the five most frequent responses were
  - Add a review of videos at the beginning of class (13.2% of students)
  - Requires a lot of discipline to watch videos ahead of class (10.5% of students)
  - Course too hard (10.5% of students)
  - Method takes time to get used to (5.3% of students)
  - Give more handouts/note booklets (5.3% of students)

Concerning the strengths, the videos were again clearly appreciated as about 40% of the respondents mentioned them positively. Another comment which is interesting to emphasize is the fifth one:



(a) Workload Question 1



(b) Workload Question 2

Figure 5: Course Workload: Results of questions answered by the students in the course evaluations.

the course offered a variety of help tools. Each different teaching strategy, whether it had to do with videos at different paces, the flipped classroom, peer-to-peer discussions, note booklets with team problem solving activities, etc., had the potential to appeal to different learning styles.

For what needs to be improved, even though many individuals believed the flipped sessions could benefit from a review at the beginning of class, this might discourage students from viewing the assigned video since they could try to rely solely on the summary to get by. In addition, despite the improvements on Mazur's method presented here, some students still believed it took too much time to get used to, as well as too much discipline. These comments regarding the discipline required or the adjustments necessary to the peer-instruction method are to be expected as they have been reported many times before. Nonetheless, considering all the other indicators of the success of this implementation, it is possible to believe that the measures put in place effectively dampened these difficulties. It is worth mentioning that this flipped method was new to the students involved and none of them had experienced it before. Few had actually heard of anything resembling it.

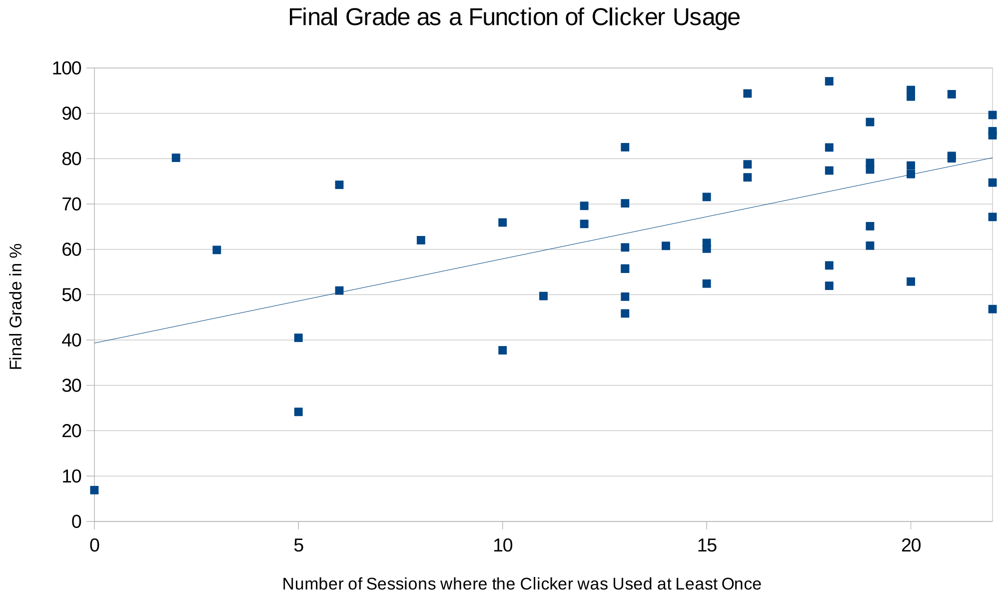


Figure 6: Final grade of students as a function of the number of classes in which they used their clickers at least once (n).

3.3 Participation with Clickers

We briefly comment in this section on the usage of clickers. As previously mentioned, a small percentage (2%) of the students final grade was linked to their in-class participation. This participation mark was measured with the clicker usage: when students attended a flipped session and submitted an answer at least once during the session, they were awarded one point. At then end of term, they had cumulated a total of n points, the possible maximum being 22. Their participation mark p was then selected to be

$$p = \frac{\min\{18, n\}}{18} \times 2\%.$$

To observe the effect of in-class participation on the final grade, Figure 6 displays the final grade as a function of n. The coefficient of correlation associated with the trend line is $r = 0.54$ which indicates a moderate association between the variables. The fact that many students did not obtain a full final participation mark appeared to be often due to them forgetting their clickers at home, and that is why we set the threshold for a perfect score to 18. In addition, even though this participation mark p was not as high as we would have hoped for most students, we believe that the 2% allocated to clicker usage at least encouraged them to initially purchase (or borrow) a clicker for the term. This in turn might have had the effect of increasing the number of students who decided to embrace the experiment and regularly use their clickers. However, since no data was collected to substantiate this claim, it remains anecdotal for now. It would also be interesting to investigate whether a larger percentage allocated to p (say 5% instead of 2%) would translate into higher values of p at the end of term.

4 Conclusions

The Mazur peer-instruction method with the proposed variations was well received by students. The videos produced at two different paces was recognized to be one of the strengths of the course and might have contributed to students regularly watching them. When building videos, the additional effort of making a second pace was not overly demanding and seems to be worth it. In comparison with a more traditional lecture-based approach, students felt the new method provided a better learning experience. They were more engaged and they did not perceive an added workload compared to previous years. The diversity of help tools available (videos, ConcepTest questions, activity booklets, etc.) is another aspect acknowledged to be a cause of the success of the course. The variety appears to have appealed to many students with different learning styles. For future research concerning videos at different paces, given the success of this experiment, more data should be collected, for example by setting up a study where different groups of students would be given different options. The idea of grouping in-class ConcepTest problems by topic would also benefit from more research. It would be interesting to use different categories and links to videos, for example by using a grouping with course objectives.

As a general comment for instructors interested in exploring these ideas, migrating from a traditional lecture-based course to a flipped approach might seem like a daunting task. However, it can be slowly (and successfully) integrated over the course of many iterations. Indeed, 30% of the classes were not flipped for the current experiment, and we believe this also contributed to the wide approval of the method by students. In addition, several options may be available to create videos for a flipped course. Indeed, many videos on a variety of topics are now available online as such courses become more mainstream. Alternatively, it is more and more common in post-secondary institutions to automatically record regular lectures and make them available to students as additional resources. These recordings could serve as a basis to create a list of videos. However, while they would possibly provide more details and examples, it is our impression that they would be too long to be directly used for a flipped course (the intended flipped course would then be closer to an online course). Given our experience with the experiment presented here, we believe that not all students will completely watch them before class on a regular basis due to their length. The videos we assigned before class did not last as long as a regular lecture, with an average per flipped class of about 50 minutes assigned (for the slower paced videos) versus 90 minutes for a regular lecture. Moreover, they were separated into shorter clips so that they only introduce one concept each. That way, it was easier for students to watch one, take a break, and then watch another later on. It also made it easier for them to review the material later during the term, for example before an exam. Despite this, we believe that if the recorded lectures could be edited somehow to break them down into shorter clips presenting only one concept each, and then they could possibly replicate the slower paced videos presented in this work. They could also just as well complement an already existing list of shorter videos and thus increase the variety in the video offering, which as we saw here appears to translate into better student participation.

Finally, the analysis conducted in this work did not include a comparison of the students academic performances between the traditional and flipped iterations of the course. As the grading scheme employed for the different evaluations was changed the semester the flipped experiment was conducted, it would have been hazardous to draw conclusions from the data. However, it would be very beneficial in the future to establish such a comparison.

Acknowledgement. While conducting this experiment, the author was supported by a scholarship from the Natural Sciences and Engineering Research Council of Canada (NSERC) and by a fellowship from the University of Victoria. The author also wishes to express his gratitude to Dr. Alfonso Gracia-Saz for his inspiration and guidance.

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