Paper ID #19088

Initial steps toward a study on the effectiveness of multimedia learning modules in introductory physics courses for engineers

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Abstract: There is overwhelming evidence that students rarely, if ever, critically read the textbook before class. The inevitable lack of student preparedness is anathema to creating an active and engaging classroom environment. Web-based multimedia learning modules (MLM) and short assignments due before lecture should allow students to enter class having more than a passing familiarity with the material to be covered. Consequently, professors can devote more class time to higher cognitive activities.

However, the literature has reported mixed results on measurable student gains when MLMs are incorporated into the typical two-semester introductory physics course-sequence. Additionally, there has been minimal physics education research (PER) on MLMs within the setting of smaller terminal bachelor's degree engineering programs, as most PER research occurs at large research institutions.

Our study's goal is to test the efficacy of incorporating commercially available web-based MLM content into introductory physics courses at Wentworth Institute of Technology, a small program that offers terminal bachelors in engineering. The study will be separated into the following two stages: stage one will consist of two professors instructing calculus-based Engineering Physics I and II, both with and without MLMs from various providers. In the fall term, we plan to use *FlipIt Physics* MLMs. In the spring term, we will use Pearson's *Mastering Physics* MLMs. We will report on the initial results from stage one at this meeting. Stage two will begin in the following year, when much of the department will adopt one of the two previously mentioned MLM platforms. All participating faculty will instruct sections, both with and without MLMs. Faculty will not be required to change their instruction styles. In addition to partially standardized metrics such as exams and iclicker performance, we plan to use the standardized Force Concept Inventory (FCI) to measure student gains in the first semester of the introductory sequence and the Concept Survey for Electricity and Magnetism (CSEM) for the second semester. These metrics will be used to compare the effectiveness of the MLMs on both an individual and department wide basis.

Keywords

Multimedia Learning Modules, Prelectures, Physics Education, Physics Pedagogy. Introductory Physics, Engineering Physics.

1. Introduction

Over the last twenty years, numerous advances in physics education research (PER) as well as the development of non-traditional learning tools have changed the landscape of STEM education [1]. A short time ago, the most widely accepted approach to physics education was the traditional lecture, supported by a hands-on laboratory component, with typical homework exercises. Demonstrations and group work added an active component to these techniques, but the overall learning process was a passive one.

The classroom was made more engaging and interactive with the implementation of technology such as live data collectors and clicker exercises [2] to gauge real time understanding of concepts. These methods typically help supplement traditional learning. Other alternatives which have shown gains in material retention include examples such as scale up and studio physics [3]. As Internet access increased, online videos, homework systems, and various other media-based activities have helped to make the classroom accessible outside of normal instruction time.

However, even with these advances, many instructors still teach in highly traditional lecture formats with pen and paper homework. There are numerous reasons cited for a return to education origins. First, many instructors are driven to teach in the methods they themselves have been taught. Second, when it comes to large scale overhaul of pedagogy, which requires infrastructure modifications such as a studio or scale up setting, capital investments are usually non-accessible to departments. Even some multimedia modules for homework and learning materials (dependent on the platform) can be expensive for institutions and students alike, and are sometimes impractical depending on the socio-economic makeup of the student population. Third, it would be imprecise to view the lecture model of the last several centuries as an unsuccessful one. Many professors are hesitant to shift from a proven model to novel and much less tested approaches. At the same time, certain subsets of students are not fully served. Most desirable then are new tools which improve gain and retention without introducing undue burden on instructors or students.

To try and study the efficacy of a singular tool, the authors chose to focus only on the usefulness of multimedia learning modules (MLM), as a supplement to a traditional textbook. We felt that it would be interesting to ask the question; Would there be a significant improvement in introductory physics students' performances at a small four-year college if a department simply adopted an MLM component to their introductory courses, without changing existing infrastructure, textbooks, or asking professors to change their lecture style?

2. Goal

In today's dynamic education market, there are numerous MLM tools available. For this study, the authors wanted to explore a robust MLM, which makes use of video lectures, embedded video quizzes, and homework assignments tied to the MLM. It should be noted that typically these types of MLM's are used in "Flipped" classrooms, where the MLM is used to completely replace traditional instruction [3 - 6]. However, this is not the focus of this study.

Many studies have shown that students do not read or retain material from passive activities such as reading standard texts [4, 7]. MLM materials offer a more engaging alternative via pre-lecture videos and reading comprehension questions, better preparing students for in-class instruction [4 – 6]. It is hoped that MLMs will work cooperatively with the textbook, which is not necessarily affiliated with the MLM platform. The textbook should reinforce the MLM content and the MLMs should help students become more critical readers.

However, it is reasonable to also expect that for many students, the MLMs will be comprehensive enough to replace the textbook entirely. On the one hand, we feel that doing so would deny students the valuable opportunity to practice learning via the critical reading of a textbook. On the other hand, if the gains are significantly greater when using MLMs, then the risk that MLMs encourage students to not use the textbook might be acceptable.

Our goal is to evaluate the advantages and disadvantages of using MLMs as an extension to the traditional learning environment. While we can expect certain populations to gain from the experience, this may not be true across the board. Our aim is to quantify any improvement in the learning experience and weigh those against the difficulties to both students and instructors of implementing these modules.

3. Implementation

3.1 Setting

Wentworth Institute of Technology is a small sized four-year engineering college in the heart of downtown Boston, where we typically offer over fifty sections of introductory physics per semester, at a section size maximum of 30 students. The total student population is 3800 undergraduate students, which is roughly 77% male and 23% female. One of the challenges of this environment is that on a given day, all classrooms are used at about ninety percent capacity. Hence, we do not have the facilities or infrastructure to move our massive amounts of introductory physics courses into a studio or laboratory based setting for some of the larger scale pedagogy initiatives. Further, with such saturation of our overall facilities, professors are typically never in the same classroom twice per day, making even tasks such as carrying demonstrations or spontaneous live experiments cumbersome. The setting at Wentworth is not unique and we believe that our findings will benefit similarly sized institutions that are considering the inclusion of MLM content in their introductory physics sequence. Conducting the study at Wentworth will also help improve the PER literature’s deficiency of investigations at non-R1 universities

3.2 Control and Experimental Group

We implemented our initial study with two different faculty members, both using similar teaching styles. The typical classroom setting consists of a combination of traditional lecture content prepared by the instructors (not a universal slide prepared by the department or supplement provided by the MLM), example problems, clicker questions, and group work. All courses are comprised of two 75-minute lectures per week, as well as a one 110-minute laboratory period once per week.

Each professor taught at least two sections of the same course at different times during the day. For each faculty member, one of their sections served as the test group, while the other(s) were used as control. The control classes were taught without MLMs using typical textbook reading assignments, and online homework through the textbook publisher, Pearson. At Wentworth, the textbook, Pearson's *University Physics* 14th edition by Young and Freedman, and the online system, *MasteringPhysics*, is standardized throughout the department. In the test group, no in-class instruction was changed, however the chosen MLM platform was deployed in addition to the textbook reading.

In the fall of 2016, one professor was responsible for implementation in the Engineering Physics I course (mechanics), while the other was responsible for implantation in the Engineering Physics II course (electromagnetism), allowing us to control for course content. The MLM platform used during the fall of 2016 was *FlipIt Physics* by Macmillan Learning. In the spring of 2017, both professors taught Engineering Physics II. To allow for a comparison between products, the faculty used the MLM portion of *MasteringPhysics* offered by Pearson in the spring.

FlipIt Physics is composed of three pieces - prelectures, checkpoints, and homework. The prelectures consist of comprehensive calculus-based and/or algebra-based video lectures. Professors also have the option to upload additional custom content. As a type of formative assessment, the prelectures contain questions to check student understating, which are graded on participation rather than correctness. The checkpoints are additional (typically conceptual) questions testing the prelecture content that are due before each class. As a form of summative assessment, the homework component consists of a few multipart quantitative questions. The platform has pre-packaged prelecutre, checkpoint, and homework questions, but the professor has the option to completely customize the assigned questions.

The *MasteringPhysics* platform is composed of two pieces – prelecture and homework assignments. The prelecture material is selected by the professor from available reading comprehension, tutorial, and video content. These follow closely with the content from the textbook but can offer additional video explanation and interactive questions. Tutorials are structured to step students through required problem solving skills. The homework section includes all questions from the textbook chapter, with the option to randomize variables. Extended questions and adaptive follow-ups are offered beyond the text content.

For all practical purposes, the day-to-day operation was identical from one section to the next, including topics covered, lecture content, and laboratory experiments. Due to the small class sizes at our institution and the limited scope of our initial trials, our data set is relatively small. In the fall of 2016, the Engineering Physics I (mechanics) sections, the control group had a total of 45 (39 male and 6 female) students and the test group consisted of 23 (19 males and 4 females) students. For the Engineering Physics II sections, the control group had a total of 17 (9 males and 8 females) students and the test group consisted of 17 (10 male and 7 female) students. In the spring of 2017, the Engineering Physics II cumulative totals were 64 students (56 male and 8 female) for the control group and 33 (29 male and 4 female) in the test group. Although the population studied in this initial survey was small, we can detail several different metrics for discussion.

3.3 Metrics:

Physics education research has developed subject specific Concept Examinations (CE) as a useful tool for the measurement of overall retention and gains in knowledge. We use these standards to assess if the MLM test groups show an appreciable gain in conceptual understanding as compared to the control. For the Engineering Physics I, the well-studied Force Concept Inventory (FCI) [8] was used as this metric, while the Concept Survey of Electricity and Magnetism [9] was used in the same capacity for Engineering Physics II. In each case, the CEs were administered at the beginning of the course and again at the conclusion. In addition to CEs, the Physics I courses used clicker questions in the classroom setting as a formative assessment. Final exam scores are also offered as a summative benchmark to compare control and test groups.

4. Data and analysis

To measure if there is a measurable statistically significant gain in using an MLM, a p-value was determined using a one-tailed t-test. Table 1 and Table 2 show that for both Physics I and II there was a positive, statistically significant, and "large" to "very large" effect size [10] on the average normalized gain (NG) [11] for both the control and test group. We can surmise that by the end of the semester, our students have gained conceptual knowledge to a statically meaningful degree in all cases. The large average NGs for the FCI is comparable to those from other studies, showing a greater response than traditional lectures, but less than completely "interactive engagement" [12].

Class	Group	Avg. NG (%)	NG Effect Size	NG p-value	Raw Final Exam (%)
Physics I (FlipIt)	Control	36	1.3	< 0.01	65
	Test	28	0.9	< 0.05	67
Physics II (FlipIt)	Control	12	0.7	< 0.01	68
	Test	20	1.4	< 0.01	61
Physics II (Mastering)	Control	24	1.5	<0.01	60
	Test	21	1.1	<0.01	64

*Table 1: Data on the average normalized gain (NG) associated with the pre- and post-test CE data for both the control and test group (*FlipIt or Mastering*) from Physics I and II. There is a large, statistically significant pre- to post-test gain in all cases. Raw final exam scores are also reported for each group.*

However, comparison between the control and test group with respect to the FCI, CSEM, and Final exam score metrics has yielded, at best, a "small" to "very small" effect size and appears to be statistically insignificant for this sample size. In other words, while the MLM students gained knowledge at a similar level to those in the control, they did not outperform their peers to a measurable degree. Other studies [5] have shown statistically significant, but similarly small effect-sizes between control and test (MLM) groups using common final exam scores as a metric.

Class	Avg. NG Difference (%)	Avg. NG Difference Effect Size	Avg. NG p-value	Raw Final Exam Difference (%)	Raw Final Difference Effect Size	Raw Final Difference p-value
Physics I (FlipIt)	-8	0.2	0.3	2	0.04	0.8
Physics II (FlipIt)	8	0.38	0.12	-7	0.34	0.13
Physics II (Mastering)	-3	-0.13	0.42	4	0.15	0.33

*Table 2: Comparison of the CE average NG difference and the Final Exam difference between the control and test group (*FlipIt or Mastering*) from Physics I and II. The effect of incorporating either MLM is not statistically significant for any case (and even if it were, the effect size is small).*

We also examined the FCI and CSEM post-test scores on a per question basis for each type of MLM, as seen in Fig. 1. The y-values are associated with the test group and the x-values correspond to the control group. A nearly equal number of points sit above the $y = x$ (solid) line as below for all classes, indicating little to no difference when comparing the control and test groups' performance on their respective CEs. Taking the data of Table 1 and 2 and Figure 1 together, we see no measurable improvement from the use of either *FlipIt* or *MasteringPhysics*.

The lack of measurable improvement is also evident in additional metrics we examined. Due to the timing of this manuscript, we only present the additional data from fall 2016 semester here.

Peer instruction [13] was utilized via clickers in both the control and test group. We found little to no gain on clicker questions performance for Physics I control and test groups, as seen in Figure 2. We found similar Average NG by males/females in the control and test groups from Physics I, and slight improvement by females in the test group as compared to the control group for Physics II, as seen in Figure 3.

When comparing NG by SAT math scores, we grouped students into three categories - low (<600), medium (≥600, but ≤650), and high (between 650 and 800). The authors expected and found a larger NG for students with medium to high SAT math scores. This is likely because these students are better prepared for the rigors of the college environment. Though a difference between the performance of the test and control groups is noticeable, the small numbers involved and relatively large error bars make us hesitant to draw a clear distinction between the two approaches for this sample. Future work may better illuminate distinctions in the teaching strategies employed over a diverse student population as our sample size grows with the inclusion of more faculty. Finally, a soft metric of gathering student feedback was compiled using student course evaluations, with targeted questions about the tools employed in the semester. Common themes and sample comments from students (positive and negative) are included in Appendix A, with some possible conclusions drawn by the authors. We feel this information is important to include as the student experience is an integral part of the learning environment. Of course, student impressions of usefulness may or may not match the data.

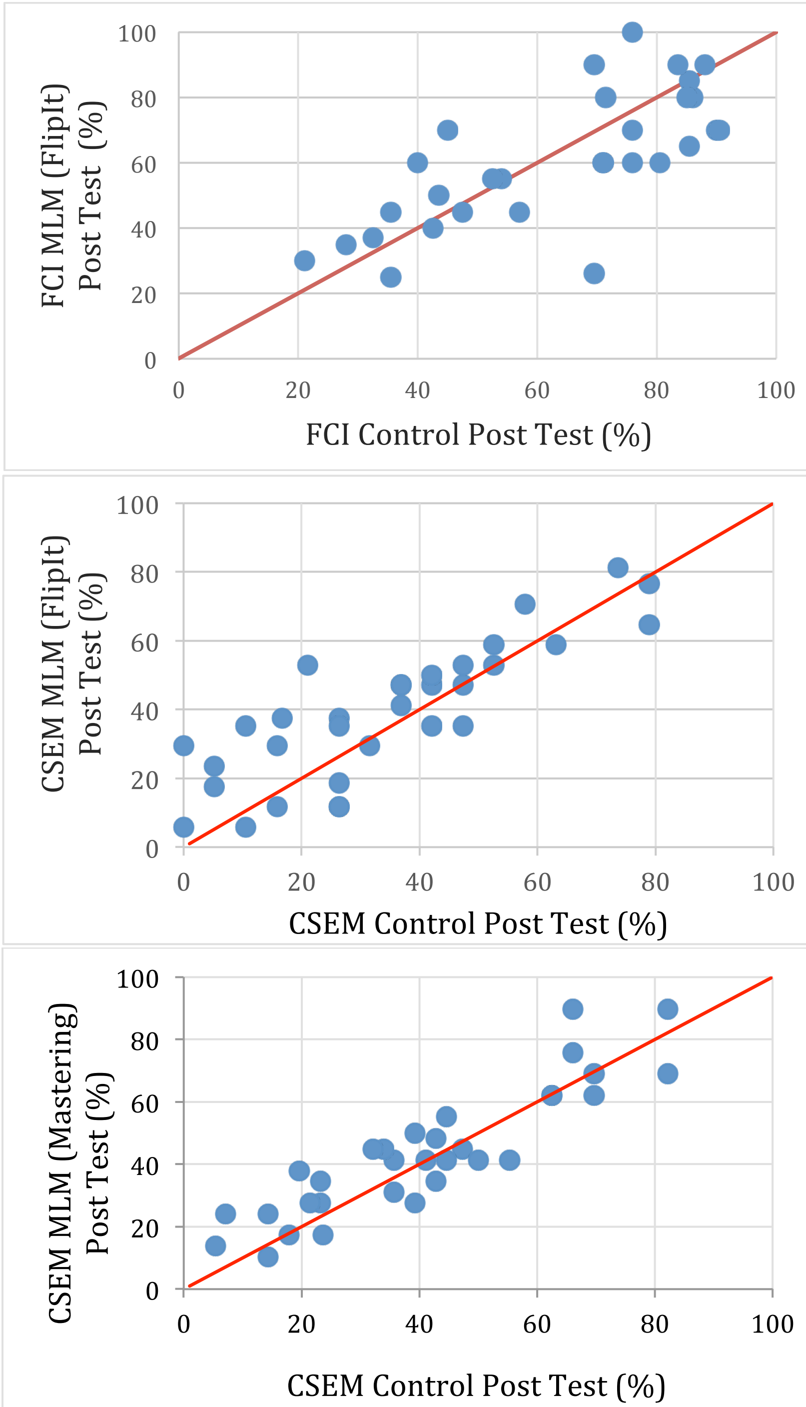

Figure 1: Each data point represents a single question on the FCI (top) or CSEM (bottom two). The y-value of the data point corresponds to the percentage of students from the MLM test group that got the post-test question correct and the x-value corresponds to the fraction of students from the control group that got the same question correct. The solid line sits along y = x. An overall benefit of a particular MLM system would be evident as a majority of points above the line.

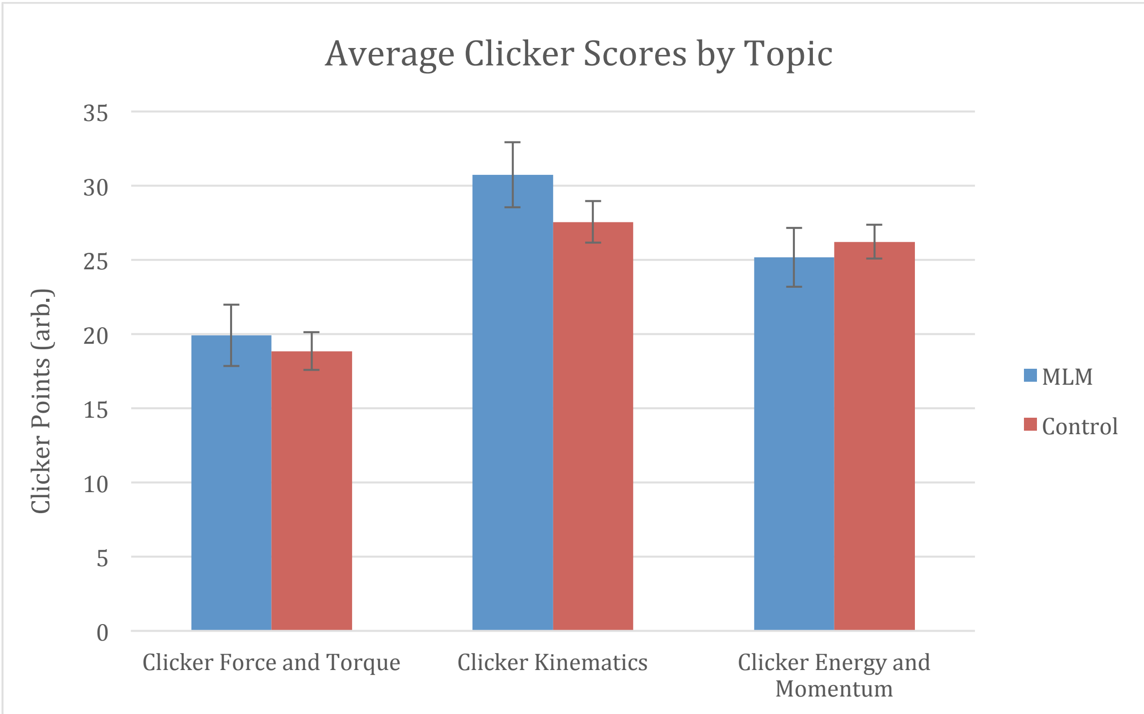

Figure 2: Average total clicker points (based on correctness, not participation) from the Physics I control group and test group. The clicker points have been grouped into the three main topics covered in Physics I, Forces/Torques, Kinematics, and conservation laws (i.e., energy and momentum). The error bars are one standard deviation of the mean.

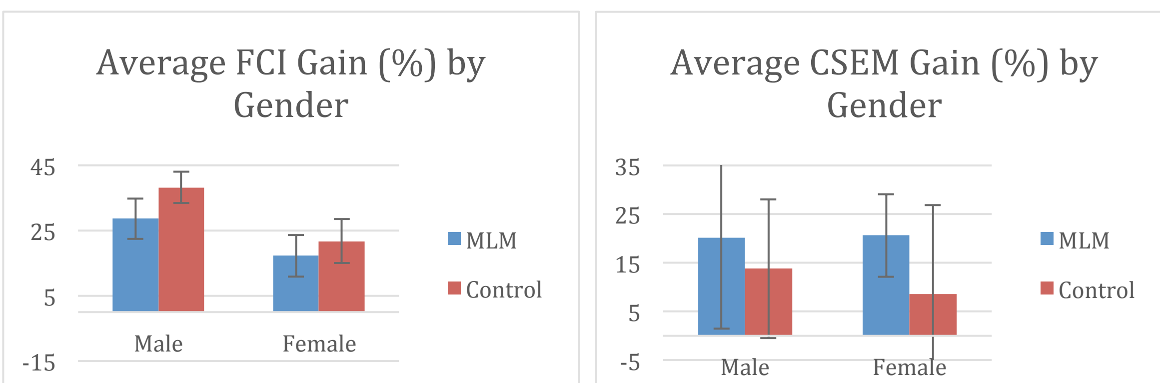

Figure 3: Average FCI NG (left) and CSEM NG (right) broken down by control and test group for each gender. While a difference in gain is evident, the variability implies no significant improvement for males or females when comparing the control and test groups for the FCI and a slight improvement overall for the CSEM group. The error bars are one standard deviation of the mean.

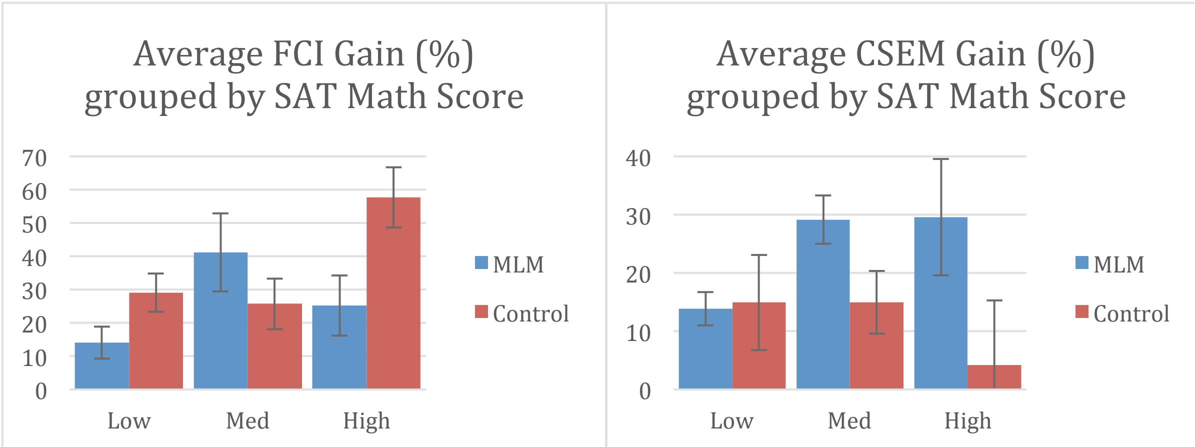

Figure 4: As expected, students with a stronger mathematical preparation show improved gain over their less prepared counterparts. While MLMs may improve gains for certain subsets, over the two courses together we see no overall trend recommending one method above the other.

5. Conclusions

An important consideration to the future implementation of MLMs is the experience from the point of view of the instructor. The two products used in this study varied in their use of media and implementation. *Flipit Physics* is a more fully featured product including readymade content and accompanying problems. This makes deploying individual content modules especially convenient. However, this comes at the cost of flexibility, making it difficult to arrange subsets of the subject matter. This contributes to an overall confusion in scheduling and grading not lost on the students. The MLM components of *Mastering Physics* are easily constructed along with the weekly homework assignments. This allows a high degree of variability, but requires much more setup time. Moreover, the selection of comprehension questions and tutorial videos available to date are limited. While it is important to acknowledge the limitations of these systems, we likewise recognize that any choice will bring its own advantages and disadvantages.

With MLM's and other online media being so readily accessible to students, as well as the fact that modern students tend to be more reliant on technology as opposed to textbooks, one might expect a large impact on educational gains. The authors, however, find mixed results in using MLM's as a supplement to traditional teaching styles. At present, no meaningful gains in student knowledge are evident from the use of MLM's alone. It may be the case that such modules require a completely transformed classroom model to be effective. Such an ambitious undertaking may not be possible at smaller institutions without university and department-wide support and significant restructuring of both facilities and schedules.

Nevertheless, MLM's more closely match the style with which students seek information through modern media. A study on their effectiveness must therefore also explore the impressions and ease of use of such material from both student and instructor perspectives. It is clear, however, from the analysis in this work that small sample size of this initial study, while still statistically significant, inhibits more far reaching analysis.

This will be improved in the future as work in process continues to increasing the testing population. Further, we are working with other faculty to begin implementation into additional courses to check for effectiveness without varying teaching style.

Acknowledgements

The authors would like to thank Johny Delaluna from Flipit Physics for providing trial materials and licenses for faculty and students for this study. The authors would like to thank Dr. James Wells for valuable discussions on the topic of MLM's and their implementation in introductory courses. Lastly, the authors would like to thank Dr. Nate Derbinsky for his assistance with data acquisition for this study.

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Appendix A: Student Responses

As mentioned in the main body, the authors also collected some feedback information from students. This type of information is interesting since the students are the ones directly interacting with the MLM, but the instructor has to identify learning gains. Below, we provide a summary of the questions asked to the MLM groups, with the initial conclusions drawn by the authors. It is important to stress once more that these results are only reflective of the groups who used the MLM in the fall semester due to time constraints.

Question 1: “What was your opinion on the effectiveness of the FlipIt Physics product?”
Sample Positives

- “I think the success I had in this class can be attributed to how prepared I was for the lectures.”
- “I really enjoyed Flipit physics it kept me organized and helped me understand.”

Sample Negatives

- “The prelectures didn't really help. They just threw a ton of info at us, the in class lectures helped more. The homework portion was very annoying, especially with the poor feedback it gave”
- “It is a great concept, but they throw too many equations at you in 2 minutes so you don't understand. They are hard to follow along with. They are also super boring so it is hard to pay attention sometimes. Lots of students didn't even watch the videos because it is really easy to just skip over them.”

Initial conclusions – The responses are quite split at about 50% positive and 50% negative. Several complaints were specifically with the HW, e.g., “Very useful although buggy”, or “The homework portion was very annoying, especially with the poor feedback it gave” and not necessarily the prelecture portion of the website. Students did not seem opposed to the concept of MLMs, but felt that the platform needed improvement.

Question 2: “Did you frequently search for and use free informational videos or lecture content found on the internet, e.g., on YouTube or Khan Academy? (Answer Choice Yes/No) If they answer yes, then "What website did you find most helpful?”

- 79% of the test group answered yes and 70% of the control group answered yes.
- The two most popular alternative sources of free, online lecture content were from KhanAcademy and YouTube.

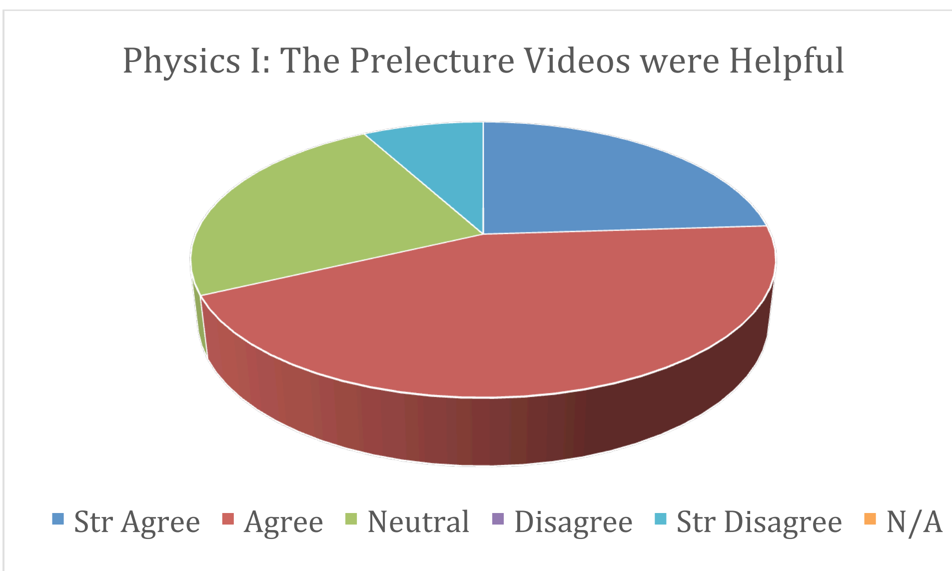
Conclusions – The large fraction of "Yes" responses suggest that students do value learning from online video content, and seem to identify as using the MLM. However, it will be interesting to compare this when future data is obtained to the actual gains by students. The authors believe that this could provide insight into a student's ability to identify their own proper learning methods and will be explored in the future.

Questions compare control/test groups

1. On average, how many hours a week did you spend on homework? (Answer choices: 0-1 hours, 1-2 hours, etc.). Conclusion – in both control/test groups most students were in the 3 – 4 hour or 4 – 6 hour range.
2. On average, how many hours a week did you spend reading your textbook? (Answer choices: 0-1 hours, 1-2 hours, etc.) Conclusion – in both the conrol/test groups most students were in the 0 – 2 hour or 3 – 4 hour range. It's possible that the prelectures discouraged reading in the test group since 80% where in the 0 – 2 hour range as compared to 58% in the control group.
3. To what extent did you find the homework assignments helpful in succeeding in this class (Scale 1-5) – Conclusion, not much difference between control and test, basically 61% of the control group and 76% of the test group strongly agreed or agreed that the online HW was helpful in succeeding. Remember, the control group's online HW was *MasteringPhysics* and the test group was FlipIt Physics.

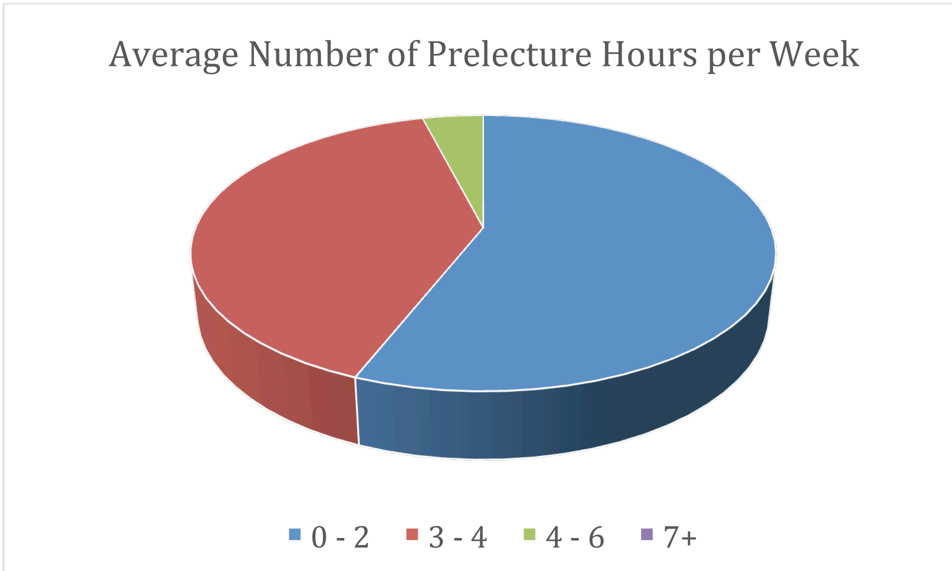
Question for test group only

1. To what extent were the pre-lecture videos helpful in understanding the topics covered? (Scale 1-5)



Conclusions - slightly better results than the free response text. Nearly 70% Str. Agree or Agree that the prelecture videos were helpful.

2. On average, how many hours a week did you spend on prelecture/checkpoints? (Scale 0-2, 3-4, 4-6, 7+)



Conclusions - nearly all students are at least devoting 0 – 2 hours per week with 40% devoting 3 – 4 hours per week, which is the approximate amount of time that you'd like them to devote reading and preparing for class. Meanwhile, less than 40% where reading for 3 – 4 hours in both the control and test group.