IMPROVED PERFORMANCE VIA THE INVERTED CLASSROOM

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Lecturing in the classroom has been the historical method of delivering information to students at the university level. However, this method of delivery has been shown to not be the most effective with millennial students (born between 1982 and 2005)[1, 2] that are our current traditional college-aged population. These students have had technology consistently in their lives and particularly computer use is an integral part of their personal and education experiences.[3]

Active learning, where students do something course-related in the classroom other than just watching and listening to the instructor and taking notes, has been used for a while in higher education and has been shown to improve student learning.[4-7] The flipped or inverted classroom is the extreme of active learning where all lecture material is delivered outside of class (by online videos or other modules) and the time spent in class is dedicated to working on problems or projects, asking questions, and taking assessments. The inverted concept is not novel,[8] but improved technology and software along with the ease of implementation has made the inverted classroom recently accessible to a large number of faculty without significant assistance.[9]

Using the inverted classroom, student performance has been shown to be improved compared to a traditional lecture version of the course. Various metrics were used to show improved learning including pre- and post-material testing compared to a previous year,[10] content coverage whereby students' time to comprehend material is shorter compared to previous year as measured by examinations,[11] and through self-evaluations via surveys.[9] Some studies have shown no significant student learning enhancements.[12] However, there are subtleties in the way the inverted classrooms are implemented that could account for the differences in measured student learning enhancements. For example in an inverted classroom study by Lape and coworkers[12] students were not given daily assessments to force their watching and understanding of material in advance of class. The first 10-15 minutes of class were spent reviewing the material from the videos; therefore, students could gain knowledge of material presented in the videos from the instructor without ever having to watch them. At the end of the class period the instructor reviewed and often presented the solutions to problems done in class and therefore students could get the answers without having to do the problems. Interestingly, the investigators themselves identified that in future implementations students would be required to do some work based on the videos prior to coming to class and hence force the students to be responsible for the material. Another inverted classroom study[13] found that on average only about 50% of the students watched the lecture material before coming to class. There were no daily assessments given in this study. Pre-class work based on the lectures that had an influence on the student's grade helps ensure students' full use of the inverted class material.[14]

The literature does not present clear evidence supporting or refuting the use of the inverted classroom for improving student learning.[15] The inverted classroom can be implemented for many reasons including improving student learning, increasing student-teacher interactions, providing opportunities for real-time feedback, allowing for self-paced learning, improving the homework problems and practice provided to students, and enhancing student engagement with the material.[15]

METHOD

An inverted class was implemented in a first-semester junior-level chemical engineering thermodynamics course at Villanova University—a medium-sized private university with undergraduate enrollments of 6,800 students—in Fall 2013 and 2014 for the purpose of determining if students learned better under this mode. There were four sections totaling 108 students for an average section size of 27 students. The inverted class was compared to the previous four years (Fall 2009-2012) of traditional lecture classes consisting of

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seven sections and 188 students for an average section size of 27 students. Each class met for 50 minutes three times a week for 14 weeks. This course had been taught 15 times prior to the inverted class by the same instructor as a traditional lecture course. An identical set of course notes prepared by the instructor was given to all sections (inverted and lecture). Each section was also given identical sample problems (158) and their solutions. Three in-class exams and a comprehensive final were given to each section. All sections were given approximately weekly homework problem sets done in teams. The inverted class had video lectures assigned (one to four) for each class consisting of the same material that would have been given in a lecture class from the previous years. Daily in-class quizzes were given to the inverted class that were closed book, but a one-page hand-written set of notes was allowed along with a calculator. In 2011, unannounced quizzes were given at the end of several lecture periods. Table 1 provides a quick reference for how each course offering was handled.

Performances on the three exams and final exam were compared between the lecture and inverted classes. Identical exams were not given since these tend to be available to students and in fact were handed out by the instructor as practice exams. Instead exam questions were developed based upon historical performance of the students on the material. The exams will be the primary method of determining the performance of the students.

An exam consisted of four questions. One question was targeted to have a 60% average and the remainder were targeted to have an 80% average producing an overall average target of 75% on the exam. The exam questions from Fall 1998-2008 and their student results were used to find types of questions that produce the desired average scores. Besides passing the t-Test (described in Statistical Analysis section) to verify equal means, exam questions had to address similar concepts and have the same number of steps and types of calculations to be considered the same, but obviously they were not identical questions. Calculations were broken down into unit conversions, algebra, and calculus steps.

Approximately weekly homework sets were assigned to all sections and were completed in teams of two to three students. Homework groups have been shown to be beneficial to student learning if implemented well.[16] All homework problems were created by the instructor. Homework length and difficulty were designed to be the same from year to year. Each of the years of 2009-2012 when compared to its previous year produced statistically similar mean scores on the cumulative homework average using the two sample t-Tests for equal means verifying that the homework degree of difficulty was consistent from year-to-year. Students also reported similar hours for time spent outside of class on assignments. For the years 2009-2012, the traditional lecture model was used and all homework was completed outside of class. For the inverted class in 2013, homework assignments were identical to that of the class of 2006 (a traditional lecture class not included in this study); however, a significant amount of class time was spent allowing students to work on their homework and ask questions of the instructor. For the inverted class in 2014, new homework assignments were developed. The average homework grade for the inverted classes was not statistically the same as the any of the previous five years of classes, having a higher average (92 ± 1.8 % versus 85 ± 2.3%).

For the inverted class, lecture videos were prepared using voice and screen capture software on a tablet. The course notes provided to all classes had blanks in them and these were filled in with writing during the lecture as would have been done during a traditional lecture class. A typical 50-minute lecture was broken down into one to four videos of varying lengths. Each video was targeted at covering one topic, concept, or problem. If students were allowed to work on a problem or a question as part of the lecture as would have been done in the traditional lecture class an opportunity for them to do so was provided in the video. The time the students spent on these active-learning activities was not included in the video length. Students were required to log in to watch the videos and the system tracked student access to the videos. At the start of each class, students were given an online 10-minute quiz consisting of four to five questions on the material in the videos assigned for that class. The quizzes were closed book but each student was allowed to prepare their own page of notes for the quiz. Calculators were allowed. Each question was targeted to a particular video and aimed at the basic concepts of the lower levels of Bloom's taxonomy of learning objectives in the

TABLE 1
Format of the course each year

	Lecture Notes Provided	Practice Problems Provided	Daily Quizzes	Random Pop Quizzes	Weekly Homework	3 Exams and Final	Inverted Video Lectures	Traditional in-Class Lectures
2009	X	X			X	X		X
2010	X	X			X	X		X
2011	X	X		X	X	X		X
2012	X	X			X	X		X
2013	X	X	X		X	X	X	
2014	X	X	X		X	X	X	

cognitive domain: knowledge, comprehension, and application. Only exam questions addressed the higher levels of analyzing, synthesizing, and evaluating.

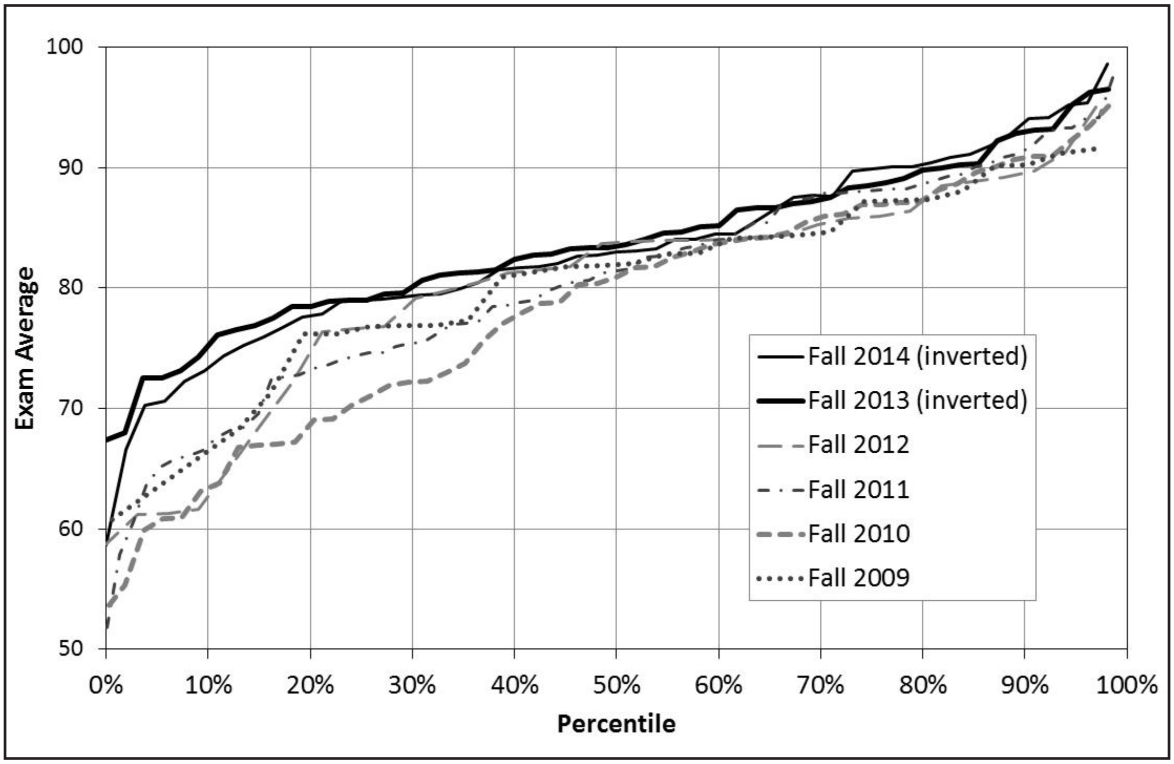

***Figure 1**. Average exam scores from the inverted classes (2013-2014) and the traditional lecture classes (2009-2012) based upon class rank percentile.*

For the lecture classes of 2009, 2010, and 2012 daily quizzes were not given. However in 2011 quizzes were given 20 times during the last 10 minutes of the lecture. These were not announced at the start of the class so students would not know if they would receive a quiz based upon the day's lecture while listening to the lecture. This was instituted to see if the students would gain more knowledge during the lecture if they were immediately held responsible for the lecture material once it was delivered. These quizzes were not given online and were open notes as compared to the 33 quizzes given during the inverted course (which were online with students only allowed a one-page sheet of notes). Both sets of quizzes addressed lower-level learning objectives and 48% of the questions were identical in both sets. A comparison of the exam results from the class in 2011 to those in 2009, 2010, and 2012 can explore the effect of frequent quizzing of the lecture material on student learning. The lecture course in 2011 with quizzes can be used as a control to compare student learning to the inverted courses in 2013 and 2014, which also utilized frequent quizzing, and potentially eliminate the quizzes as having an effect on student learning objectives.

STATISTICAL ANALYSIS

To compare two data sets to verify if they were from different populations a two-sample t-Test for equal means[17] if normally distributed or Welch's adaptation of the t-Test[18] if not normally distributed was implemented. The normal distribution was tested using the Shapiro-Wilk normality test which has been shown to be a very accurate method for testing normality.[19] A 95% confidence interval was selected for this analysis.

Averages throughout the manuscript are reported at 95% confidence intervals. The Mann-Whitney non-parametric test[20] was used to show that there was a significant difference between the average scores from one set of data when compared to another set.

RESULTS AND DISCUSSION

Exam Performance: The three exams and final exam were averaged (equal weight given to each) and the Mann-Whitney non-parametric test[20] verified that there was a difference between the averages from the lecture classes when compared to the inverted class. With all four lecture classes combined the significance value of the test was 0.031 and is below 0.05 for 95% confidence limits. If each year was examined separately versus the inverted years, there was still statistical difference between the data sets. Even the lecture course from 2011 that instituted frequent quizzes to hold students accountable for the lecture material showed statistical difference when compared to the results from the inverted class, which also had frequent quizzing. Therefore frequent quizzing alone could not account for the improved student performance observed in the inverted class. The averages for all four exams combined (equally weighted) are shown in Figure 1. The exam averages (95% confidence interval)

TABLE 2
Average exam scores (95% confidence limit) for inverted versus traditional classes. Class was partitioned based upon average exam score.

	2009-2012 (Traditional)	2013-2014 (Inverted)	Normal Distribution	t value	p value
Overall	79.8 ± 1.4	83.2 ± 1.3		3.29	0.001
Top 1/3	89.2 ± 0.7	91.1 ± 1.0		3.04	0.003
Middle 1/3	81.4 ± 0.6	83.3 ± 0.6	X	3.98	0.00007
Bottom 1/3	68.6 ± 1.6	75.3 ± 1.5	X	5.62	<0.00001

TABLE 3
Average scores (95% confidence interval) for the bottom third (partitioned using exam average) of the class based upon question type for traditional lecture versus inverted classes.

	2009-2012 (Traditional)	2013-2014 (Inverted)	t value	p value
Overall	68.6 ± 1.6	75.3 ± 1.5	5.62	<0.00001
Questions 1-3	70.9 ± 0.4	76.0 ± 0.4	4.89	<0.00001
Question 4	60.1 ± 0.6	73.7 ± 0.6	5.56	<0.00001

are also presented in Table 2 along with t and p values from the two-sample t-Test for equal means[17] for normal distributions or for Welch's adaptation when the distributions were not normal.[18] The bottom and middle third averages were normally distributed while the overall and top third averages were not.

Interestingly, the lower third of the class (based upon exam average) performed significantly better in the inverted class compared to their lecture-class counterparts. Their exam average went from a D+ to a C on the traditional grading scale, improving almost seven points. The top third of the class only increased exam averages by two points. It is important to note that the qualifications (cumulative GPA and math and verbal SAT scores) between these classes were not statistically different. For example the inverted cohort had their SAT scores only 1 point higher than the traditional cohort and the populations were deemed identical.

As noted before, each exam consisted of four questions. Three of the questions were targeting an 80% average while the fourth was targeting a 60% average. The first three questions addressed the fundamental lower-level Bloom's Taxonomy in the cognitive domain of knowledge, comprehension, and application learning objectives while the more difficult problem also required analysis, synthesis, and/or evaluation. Since the bottom third of the class performed significantly better on their exams it was desired to see if their skills increased across Bloom's Taxonomy. Exam averages were created using just the first three problems and then another average created using just the fourth problem across all exams. In all cases the scores were normally distributed. The results are shown in Table 3. Similar trends were not observed in the better performing students.

In all groupings the exam averages were higher for the inverted cohort compared to the traditional lecture cohort and the data sets are different. For the traditional lecture cohort the averages from questions 1-3 were statistically different than the averages from question 4 using the Mann-Whitney non-parametric test.[20] For the inverted cohort there was no statistical difference between the averages of questions 1-3 compared to question 4 at the 95% confidence limit. The weaker students in the lecture course tended to perform poorly on problems requiring higher-level learning objectives compared to problems requiring lower-level skills. However, the students in the inverted course showed equal performance across exam questions addressing different levels of learning outcomes. The inverted method showed a 5.1 exam point increase in lower-level skills and a 13.6 point increase on higher-level skills when compared to the lecture method. The inverted classroom method appears to help the weaker students more than the stronger students in the course. A larger increase in higher-level skills occurs with the inverted method.

Student Perception: It has been shown that the students in the inverted class perform better than the students in the traditional lecture class. A common belief for this enhancement is that the students in the inverted class do more work or put in more time outside of class to achieve their performance enhancement. In the third to last week of the semester of the inverted classes the students were asked to rank their perception of the inverted class on a five-point scale where 1 represented strongly disagree and 5 represented strongly agree. There was one student out of the 107 who had previous experience in an inverted course before this one. The results of this survey are present in Table 4.

TABLE 4
Survey of student perceptions of the inverted classes, 1 = strongly disagree and 5 = strongly agree.

I feel the format of this course improved my overall learning compared to a traditional lecture course.	4.5 ± 0.3
I feel the format of this course required a substantial amount more time compared to a traditional lecture course.	4.4 ± 0.3
Solving problems in class prepared me better for solving problems on my own.	4.1 ± 0.4
I feel that because of the format of this course, I received more personal attention compared to a traditional lecture course.	4.3 ± 0.4

From the survey results it appears that the students believe they are putting in more work when compared to a lecture course; however, this may not actually be the case. On the last day of class anonymous course surveys are administered to the students in all courses. One of the questions asks the students in the thermodynamics course to identify on average how many hours a week outside of class they spent on this class. For the inverted sections students identified 6.2 ± 0.5 hours per week spent on the class. For the four previous years of the lecture version of the course the students reported that they spent 5.8 ± 0.6 hours per week outside of class, an average time that was shown to be statistically the same as for the inverted course using the t-Test even though there can be errors in students self-reporting data. When taking an inverted course and other lecture courses at the same time the students believe the inverted course takes much more time than their lecture courses. However, in reality they may not be spending any different amount of time outside of class on their material for the inverted class. Their time is spent differently and one might say more effectively to achieve higher exam scores based upon the course material. More of the student time is spent on the video lectures and comprehending the material and less time on the homework and studying for exams.

TABLE 5

Daily quiz averages (95% confidence interval) for inverted class in 2013 (full credit for attempt) compared to identical quizzes given to the 2014 class where quiz grades counted.

	2013 Quiz Average credit for attempt Week 6	2014 Quiz Average graded quizzes Week 6	2013 Quiz Average graded quizzes Weeks 1-5, 7-14
Overall	50 ± 3.1	80 ± 1.6	82 ± 1.8
Top 1/3	68 ± 3.7	94 ± 1.4	92 ± 1.4
Middle 1/3	59 ± 3.7	81 ± 1.4	84 ± 1.9
Bottom 1/3	23 ± 6.9	66 ±3.7	69 ± 4.3

Holding Students Accountable: After reviewing the literature on the inverted classroom it appears that students must be held accountable for the material presented outside of class. The viewing and comprehension of the material must somehow affect their course grade. This was accomplished in this study by having the students take a 10-minute quiz based upon the assigned videos every day. The quizzes were closed book but a hand-prepared one-page sheet of notes was allowed. The students had 33 quizzes throughout the 14-week course and were allowed to drop their 10 lowest scores assuming they missed fewer than two classes (unless excused for illness or other reason). As an experiment in week 6 (about halfway thought the course) in the 2013 inverted sections the students were given full credit for the 3 quizzes as long as they attempted the quiz no matter what they actually scored on the quiz; they were made aware of this change prior to the assignment of the videos. Results are shown in Table 5.

In the 2013 version of the inverted class, when students were given full credit for attempting the quiz they performed significantly worse when compared to the rest of the quizzes they took when the quiz scores counted. This was even observed for the high-performing students. The identical quizzes for week 6 were given to the two sections of the inverted course in 2014 (52 students); however, the quiz scores counted in their grade and when this occurred the students performed significantly higher when compared to their 2013 counterparts. In 2013 there were on average 1,025 videos accessed during a typical non-exam week (excluding week 6).

This corresponded to 172 student accesses per video or each student accessing each video three times on average. During week 6 there were only 435 videos accessed and there were 22 students (39% of the class) that did not access any videos that week. During all the other weeks there was never a student observed to not access videos. These results clearly show that the students must be held accountable for the inverted material before they come to class.

Effect of Frequent Quizzing: A common criticism of the inverted classroom in the way it was implemented in this study focuses on the daily quizzing, and it is postulated that it is this change in the course that improves the student learning and not the inverted method. In 2011, during the traditional lecture version of this course there were 73 students in two sections and the students were told at the beginning of the course that at the end of a lecture it was possible they would be given a 10-minute quiz based upon the day's material. They would be allowed to use their notes taken that day as well as a calculator during the quiz. Twenty quizzes were actually given during 2011. The quiz average for 2011 based upon 20 quizzes was 86% while for inverted sections based upon 33 quizzes it was 80%. The students did perform slightly better on the quizzes in 2011 than in the inverted course and if an examination of just the quiz scores was the only method for evaluating the inverted classroom one could conclude that there was no difference in student performance or even that the students in the traditional lecture class retained information better and performed better on the material. However, when examining the exam scores shown in Figure 1 and Table 2 it is clear that the inverted class performed better than the lecture class even if the lecture class was given frequent assessments to facilitate the students learning the material. Therefore it is the inverted part of the course and its implementation and not the frequent assessment that increases student performance. It is possible that the mere action of students having to summarize the notes for the quiz could

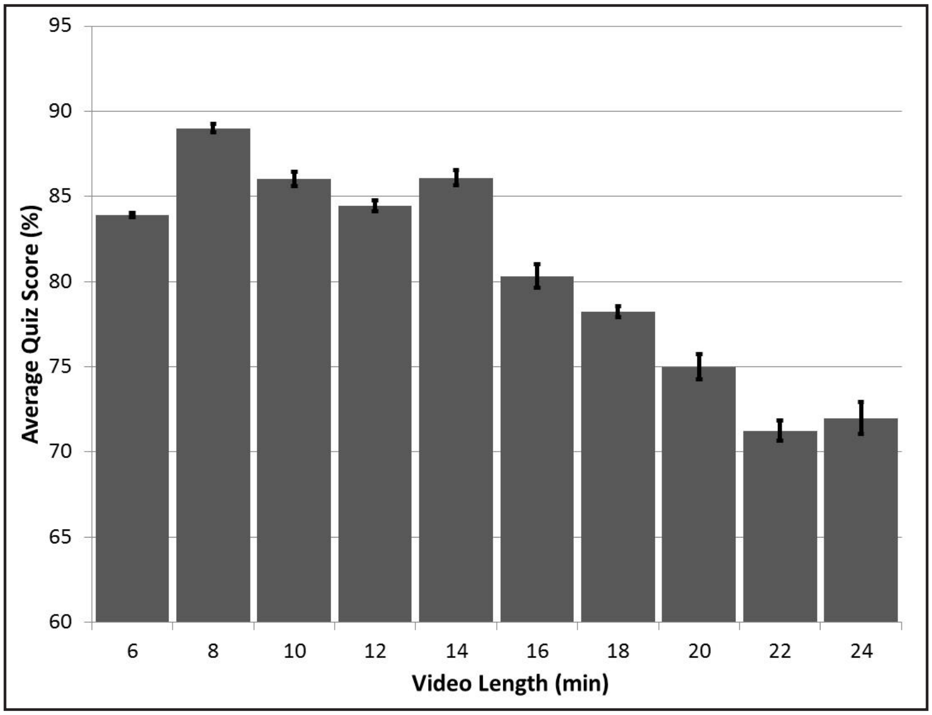

Figure 2. *Average quiz score (95% confidence interval) tracked to video length containing the material for the question. There were 64 videos for the course and some videos had multiple questions associated with them.*

also lead to improved performances and this is part of the method of implementing an effective inverted classroom that goes beyond just the recording of lectures. The ability for the students to watch the lectures when they want and as many times as they want, along with their frequent interaction with the instructor in the class while working on problems, helped increase their knowledge, understanding, and application of the course material. The daily quizzing in the inverted course helped to facilitate a level of comprehension of the material before the class so that it could be applied to problems and situations quickly during class time. The students could even go back and access the videos during the class while working on problems and often were observed doing so.

Video Length: Lectures were prepared for each class and were broken into 1-4 videos per day keeping major topics and problems in one video. Videos were then grouped into length categories by 2-minute intervals. The set of videos for each day was matched to the set of lectures that would have been given that day in the traditional lecture course. If a lecture included a break for students to work on a problem/question that break was provided in the video by asking students to pause the video and work on the problem. There was no monitoring of how long students actually spent on the problem. The time a student would spend working on a problem was not included in the measured video length. The problem/question was generally reviewed in the video by the instructor, as would have been done in the lecture course, and this time was included in the video length. Typically the traditional 50-minute class did not contain 50 minutes of lecturing as there were always some active-learning activities built into the lectures and these were maintained to keep the content delivery identical between the inverted and lecture courses. Each video also had quiz question(s) associated with it and the performance of the class on each question was tracked. Results of the student quiz scores based upon video length is presented in Figure 2.

All of the quiz questions addressed learning objectives associated with knowledge, comprehension, and application. The videos covered these learning objectives as well as those related to analyzing, synthesizing, and evaluating. Many of the higher-level learning objectives were also covered in the example problems provided to the class. There was no partial credit given on quiz responses. Students tended to test better on materials associated with shorter videos. There was a drop off in student understanding and applying thermodynamic concepts if they were presented in videos longer than 15 minutes.

After reviewing these results it was questioned whether the longer videos contained topics that were a different degree of difficulty or addressed higher levels of learning objectives on Bloom's scale even though the quiz questions only addressed the lower levels. Therefore the set of learning objectives written for the course was examined. There were 168 learning objectives previously written. These were initially developed in 2001 and edited for three years. Since 2004 they have remained the same for the course and have been provided verbatim to the students in all classes at the start of the course. The verb in each learning objective was analyzed and matched to a learning outcome in Bloom's cognitive domain using the work of Huitt[21] as a guide to help classify the objectives. Each objective was grouped into either the lower three levels or higher three levels. Of the 168 learning objectives, 81% of them were in the lower levels while the remainder was classified in the higher levels.

There were 64 videos for the course presented over 33 days of lectures. Each video addressed multiple learning objectives. The 32 higher-level learning objectives were traced to 12 videos, each being longer than 15 minutes. There were only three other videos longer than 15 minutes that did not address higher-level learning objectives. The quizzes only asked questions related to lower-level learning objectives even though the video lectures covered material across all levels. Two conclusions could be drawn from the learning objective analysis. First, for better student comprehension, topics addressing lower-level learning objectives should be separated from the higher-level ones when preparing the lecture videos. It appears students would get wrapped up in the higher-level skill acquisition and not grasp the lower-level skills as well when both were presented together. The other conclusion would be to shorten the video lengths to below 15 minutes without having to separate the different levels of learning objectives. These conclusions would need to be verified as the data cannot definitively support either one, but suggest them as possibilities.

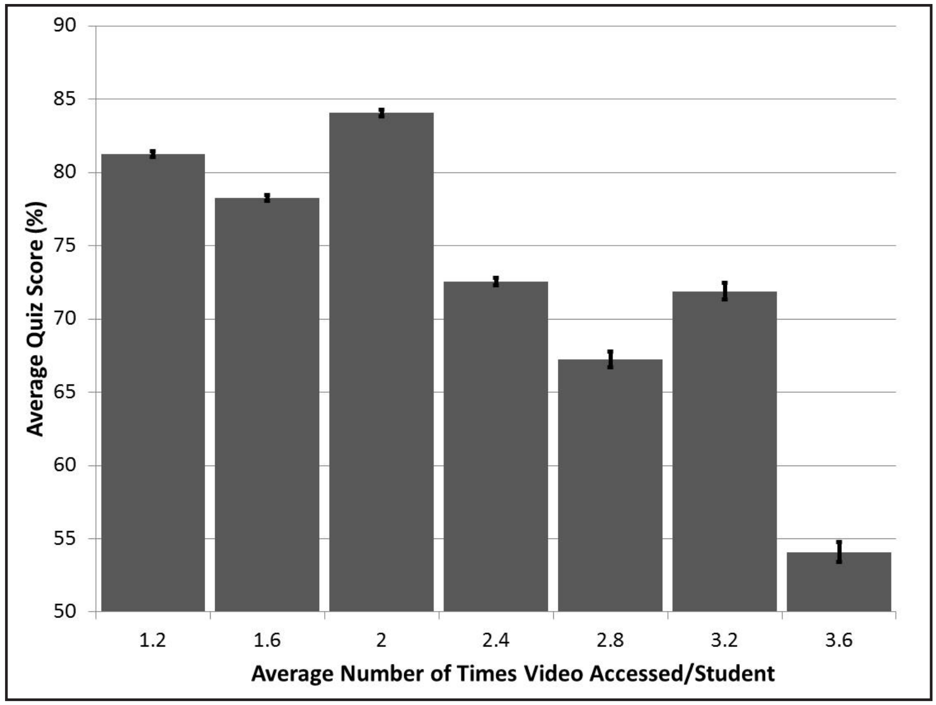

Figure 3. *Average quiz score (95% confidence interval) tracked to number of times a video was accessed. Data are a composite for all 64 videos.*

Video Access: The online system was able to track when students accessed videos. There was no correlation between the time or day when the students accessed the videos and their quiz scores. There was a correlation between how many times a video was accessed and the average quiz score on the material related to that video (Figure 3). The data were collected up until the quiz time. Students did access videos after the quiz when doing problems, reviewing materials, and studying for exams but those accesses were not included in this data.

The results in Figure 3 provide information to the instructor about what material is difficult for the students to comprehend without having to test the students. One could examine material in videos that were accessed more than twice for this course and assume students need additional instruction on this material. In fact, the instructor could, in future offerings of the course, monitor the video access up until the time of class and enter class with some prior knowledge about where the students are struggling and provide instantaneous instruction on that material via a mini lecture, an example problem, or other means.

CONCLUSION

Students in an inverted class tended to perform better on exams than their counterparts in a traditional lecture course. Students with lower exam scores saw the biggest improvement in their performance with the bottom third of the class increasing their average exam score by seven points. The method of implementation of the inverted course is important and several factors were found to be required for improved student performance. Students must be held responsible for material presented outside of class by video. This was accomplished by daily quizzing. Videos needed to be kept short as videos longer than 15 minutes were found to be not as effective in transferring knowledge as shorter ones. Tracking student access of the online material can also provide data to the instructor on student learning prior to formal assessment.

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