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Enhancing Student Performance in an Online Introductory Astronomy Course with Video Demonstrations

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Abstract

We present the effect of video demonstrations on student performance in an online Astronomy course. We find that students who watched the videos performed better on related exam questions compared to those who did not watch the videos. We also find that students in the online course performed as well as students in a nearly identical face-to-face course on video-related questions but worse on other questions. Finally, we find that online students performed at par with face-to-face students on the Astronomy Diagnostic Test. These videos are freely available on YouTube, Google Videos, and iTunes.

1. INTRODUCTION

Online courses continue to grow in popularity each year, with over 50 courses offered at Penn State University in the spring semester of 2008. This is partly because these courses allow students the greatest scheduling flexibility so that students with family or work commitments can still complete the course work. Typically, the flexibility of online courses attracts two types of students: those who are self-motivators and will push themselves to work in the course but on their own time and those who desire the freedom online courses provide but may not have the ability to structure their time effectively to keep themselves progressing through the course. Due to the presence of the latter group, concerns persist about the level of student performance in online courses compared to the level of student performance in traditional lecture courses.

A few studies involving small class sizes and single teacher comparisons have been performed by a number of instructors (Bearden, Robinson, and Deis 2002; Cooper 2001; Miller, Cohen, and Beffa-Negrini 2001; Rivera, McAlister, and Rice 2002; Smith, Smith, and Boone 2000), most of whom found that little difference exists between the online and "face-to-face" (hereafter, F2F) students in terms of performance. A more robust study, incorporating 4 years of data among multiple instructors of the same business management course (Ury 2004), found that within their larger data sample, a clear split between the two groups of students emerged. In terms of performance with their courses, traditional students performed statistically better (roughly 5% higher) than equivalent students within the same course taught online.

Sitzmann *et al.* (2006) found in a review of 92 studies of web-based vs classroom instruction that the degree of learner control positively influences the effectiveness of instruction. In essence, students do better when they are in control of their own learning. In their paper, Sitzmann *et al.* also found that one factor essential for the effectiveness of web-based courses is a larger variety of instructional methods incorporated into an online course. Simply creating a series of lessons (an "online textbook") is not sufficient. In order to make the online experience truly effective, it needs to contain components equivalent to the traditional lecture course.

In Spring 2008, we created 19 video demonstrations for students in a new online introductory astronomy course at Penn State. One of our primary motivations in creating this series of videos for the online course was to reproduce any demonstrations normally presented in a traditional F2F course within the online environment. In a review of a number of instructional design theories and models, Merrill, Barclay, and van Schaak (2008) concluded that most of these instructional design theories share a common set of principles of instruction. One of which is the demonstration principle, which states that "learning is promoted when learners observe a demonstration of the skills to be learned that is consistent with the type of content being taught." Online classes are typically missing this component that is frequently present in traditional lecture courses. We also wanted to provide students with a more dynamic presentation beyond the lesson material already provided. Students with low working memories (or low abilities to transfer learned information into long-term memory) usually prefer a visual learning style (Graf *et al.* 2006). By providing visually engaging demonstrations of a number of astronomical concepts, it was our hope to assist these students in retaining the material being covered in the videos better.

In this paper, we present the effect of these videos on student performance, specifically as it compares among online students who did and did not watch the videos, as well as students in a similar F2F course (who also did not see the videos). Section 2 describes the video demonstrations in greater detail. Section 3 presents our data and statistical analysis of these data, which we discuss more thoroughly in Section 4. Our conclusions are presented in Section 5.

These videos are freely accessible on YouTube (www.youtube.com/astronomy001), Google Video (www.video.google.com), and iTunes U (www.itunes.psu.edu).

2. VIDEO DEMONSTRATIONS

Due to the growing popularity of online courses, Penn State University decided to expand upon the number of online courses offered to students. As the course with the highest enrollment at the university, Astronomy 001 was a natural choice for conversion from a traditional course into an online course. Astronomy 001 is a one-semester course for non-science majors that covers the entire spectrum of astronomy (including the solar system, stars, galaxies, and cosmology—typically referred to as "ASTRO 101" within the astronomy education community). With the help of the Blended Learning Initiative at Penn State and Dr. Mercedes Richards of the Department of Astronomy and Astrophysics, the first author designed a series of lessons to be presented to the students using ADOBE PRESENTER. While the lessons contained learning goals, NASA images, flash animations, periodic self-test quizzes, and other pedagogical tools, for the most part they were simply an online version of a textbook. Presented with the task of recreating the traditional F2F experience within an online setting, the first author determined that what online courses lack is a physical demonstration of various astronomical concepts discussed in the lessons. With the help of the second author, he decided to create a series of videos to simulate the types of demonstrations that may typically be conducted within a traditional F2F class.

The online course was offered to students through the course management system ANGEL. The course was broken into four main units, with each unit containing three sections and culminating in an exam. The sections were designed such that they contained roughly one week's worth of material. Students were advised that if they completed a section per week, they would stay on track with the course and be prepared for the exams on time. In order to regularly engage the students with the videos, we concluded that it was necessary to have at least one video in each section of the course. Some sections naturally lent themselves to more videos, so that we ended up with a total of 19 videos covering topics from throughout the semester. The topics are listed as follows:

1. Introduction
2. Rotation and Revolution
3. Galileo's Experiment
4. Newton's First Law—The Tablecloth Trick
5. Newton's First Law—Ball and String
6. Blackbody Radiation
7. Spectroscopy
8. Angular Momentum
9. Mass vs Density
10. Composition of a Comet
11. Terrestrial Atmospheres
12. Jovian Planets

13. Uranus' Tilt
14. Plasma
15. Parallax
16. Selection Effect
17. Pulsars
18. Spiral Density Waves
19. Expansion of the Universe

While the videos were offered along with the lesson material, they were not incorporated within the lessons but rather listed separately as a supplemental resource. Students were not required to watch the videos but were highly encouraged to do so. Originally the videos were uploaded to a Penn State website and links to the videos were provided within each section after the lessons, but students began reporting problems downloading the videos. As a result, we decided to upload the videos to iTunes U (www.itunes.psu.edu) as well as Google videos (www.video.google.com), so students could have a wider selection of options for viewing the videos. After the course, we uploaded the videos to YouTube to provide additional viewing options for future courses.

3. DATA AND ANALYSIS

While the first author was teaching the online course during the Spring 2008 semester, he was also teaching a traditional F2F section of the same course. We allowed students in the F2F course to access all of the learning materials within the online course, with the exception of the videos. In lieu of the videos, students in the F2F course were presented with equivalent in-class demonstrations or similar materials. The same questions were asked on the exams in the F2F course as were asked in the online course so that we could draw comparisons between the two. In order to assess the effectiveness of the videos, we included a number of questions on the exams specifically written with the video demonstrations in mind. Of the 156 questions asked in both sections over the course of the semester, 30 of them were related to topics covered by the videos. While the material covered by the questions was contained within the lesson material, we hypothesized that students who watched the videos would perform better on these questions than students who did not watch them. In addition, we administered the Astronomy Diagnostic Test (ADT) (Hufnagel *et al.* 2000; ADT V2.0) as both a pre-test and a post-test to both sections of the course. Finally, we surveyed the students at the end of the semester to collect attitudinal information regarding the videos, as well as determine which students watched which videos. All of the information that was gathered was "anonymized" by a collaborator not specifically working with this data, and students were given the opportunity to not contribute their data to the project. While the data can only be generalized to students who would grant permission for scores to be used, in comparing results for the classes as a whole to those of the participating students, we found no significant difference in our results. Of the 317 students enrolled in the online course and the 99 students in the F2F course, 204 online students (64%) and 77 F2F students (78%) agreed to participate in this study. From these data, we hoped to determine whether or not the videos in general had any impact on student performance in the web course and, if so, which videos were most effective at boosting student test scores.

3.1. Video Benefit

To determine whether or not the videos led to a general improvement in student test scores, we compared the performance of students from three groups—those in the web course who watched the related video, those in the web course who did not watch the related video, and those in the F2F section, who did not have access to the videos.

We used a paired t-test to test the associated null hypotheses of this first data set. This test relies upon a pair of random samples, with the assumption that the paired differences are independent and identically normally distributed. In other words, when comparing two data sets, if the null hypothesis is true, then we conclude that there is no significant difference between the two data sets. The t-values and associated probabilities are provided in the table below. A positive t-value is indicative that the first sample performed better than the second sample, and the magnitude of the t-value is indicative of the difference in performance between the two samples. Averages are provided here simply for comparison and cannot be used to reproduce our calculations (Table 1).

Table 1. Comparison of web students who watched, who did not watch, and F2F students				
Comparison Sample	**Average 1**	**Average 2**	***t* Value**	***p* Value**
Web watched vs web not watched	68.4%	60.4%	3.43	0.0019
Web watched vs F2F	68.4%	62.3%	2.11	0.0435
Web not watched vs F2F	60.4%	62.3%	−0.49	0.6260

Type I error rate is the probability that a test will indicate that the null hypothesis is false when it is actually true. A typical value to choose for the Type I error rate (α) is 5%. The more hypotheses one is testing, the more likely one is to discover a significant result. Thus, the Type I error rate of 5% is divided by the number of tests (in the above case, three) per the Bonferroni adjustment (Bonferroni 1935). When the measured probability that the null hypothesis is true (p value) is less than the Type I error rate, we reject the null hypothesis, suggesting that the two sets of data are significantly different. Based on a comparison of data from those who watched the videos to those who did not watch the videos, we conclude that watching the videos is correlated with higher exam scores within the web course. Neither of the other probabilities is significant at the 0.0167 level, and so we accept the null hypotheses for these samples (i.e., there was no statistically significant performance difference between the F2F class and either subpopulation of the web class).

How do the students in the web course compare, in general, to the students in the F2F course? Neglecting the video-related questions, our null hypothesis is that students in both groups are indistinguishable. Both the web and F2F classes were given 126 identical questions unrelated to the videos. The *t*-test indicates that we can reject this null hypothesis at the $\alpha=0.05$ level. As expected, students in the F2F course performed better than students in the web course (Table 2).

Table 2. Web vs F2F (for nonvideo questions)				
Comparison Sample	**Average 1**	**Average 2**	***t* Value**	***p* Value**
Web vs F2F (nonvideo questions)	68.9%	72.3%	−2.84	0.0053

In order to quantify how much the videos helped the web students, we use a logistic model with repeated measures. This analysis takes into account the performance of the individual student, comparing every student response to the video-related questions, and whether or not they watched the video in question as the independent variable. Reviews of this technique can be found in Agresti (2002). We used a SAS script, initially written by John Hughes of the Pennsylvania State Statistical Consulting Center (http://www.stat.psu.edu/~scc/). We find that the contrast estimate is 1.43, with 95% confidence interval extending from 1.16 to 1.77. In other words, students who watched the videos have a 95% chance of doing between 16% and 77% better on relevant questions.

3.2. Individual Videos

The efficacy of the individual videos was most easily estimated from the odds ratio, which is a measure of the advantage provided by watching the video. Students and their responses to exam questions in relation to a single video can best be summarized in a contingency table as follows:

	Answered Correctly	Answered Incorrectly
Watched video X	n_{00}	n_{01}
Did not watch video X	n_{10}	n_{11}

where, for example, n_{00} indicates the number of students who watched video X and answered the relevant questions correctly. The odds ratio is then

$$\Omega = \frac{n_{00}n_{11}}{n_{01}n_{10}}$$

Higher odds ratios (>1) indicate more effective videos, while videos with lower odds ratios (<1) indicate videos that were disadvantageous. Every measurement has an associated error. Given a different group of students, how certain can we be that they would perform the same way? This concept is best quantified by "confidence limits." A 95% confidence limit indicates the range of values we would expect to see in 95% of all future online courses. In other words, we would expect one in every 20 classes to fall outside this range (and only one out of 40 classes to be below this range). The 95% confidence limits of these ratios can be estimated from

$$\sigma = \exp(\ln(\Omega) \pm 1.96 \times \Sigma),$$

where Σ represents the standard error, and is given by

$$\Sigma = \sqrt{\frac{1}{n_{00}} + \ldots + \frac{1}{n_{11}}}$$

We reject the null hypothesis (and claim that the video was helpful) if the 95% confidence limits do not flank an odds ratio of 1. The odds ratios and 95% confidence limits for 29 of the video-related questions are shown in the plot below (one video was neglected because no students who did not watch the video answered incorrectly, and thus the odds ratio was zero; (see Section 4). We also highlight two other videos that helped students at the 90% level. At this confidence limit, we would expect one out of every twenty online courses to show results consistent with no improvement from watching these videos (Figure 1).

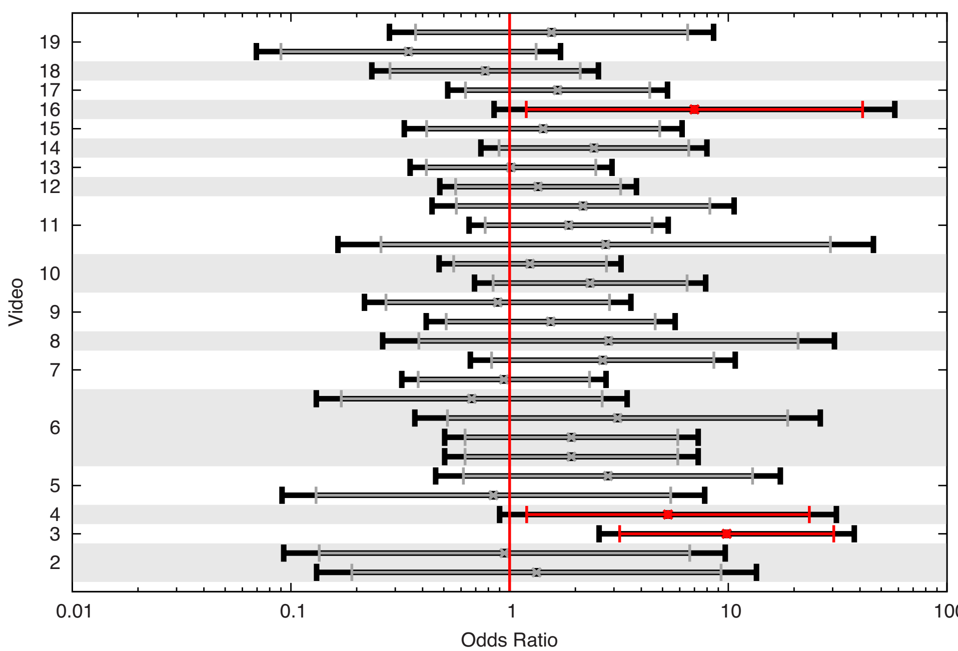

Figure 1. Odds ratios and confidence intervals for the 29 examination questions related to the videos. The outer bars represent the 95% confidence intervals while the inner bars represent the 90% confidence levels. Videos with odds ratios that span an odds value of 1 indicate statistically insignificant results. From this analysis, we see that video 3 was helpful, and videos 4 and 16 were also probably helpful. No other video shows strong evidence that it bolstered student knowledge

3.3. Comparison of ADT Results

In addition to assessing students based on their responses to exam questions, we also administered the ADT (Hufnagel *et al.* 2000; ADT V2.0) as both a pre- and post-test survey to chart student learning in the two courses. The ADT has been the most commonly used diagnostic survey used in introductory astronomy courses and had been administered to all sections of Penn State's introductory astronomy courses for the year and a half prior to the time of this study. We used a paired t-test to compare the two courses to see if there was any significant difference between the two sections (Table 3).

Table 3. ADT results. A comparison of the ADT pre-test and post-test scores between the F2F and Web sections, as well as the gain in each section

	Average (F2F)	Average (Web)	*t* Value	*p* Value
Pre-test	35.5%	33.4%	1.64	0.116
Post-test	62.8%	48.7%	5.03	6.43×10^{-5}
Gain	42.3%	23.0%	3.90	8.82×10^{-4}

We accept the null hypothesis for the pre-test comparison: at the beginning of the semester, the two sections were essentially identical. However, the probability is very low that the two sections are the same by the end of the semester. In terms of the Astronomy Diagnostic Test, students in the F2F section performed significantly better than those in the online section.

Only three of the questions on the ADT are directly related to the topics covered by the videos. Given the large uncertainty in the odds ratios of these three questions, we are unable to state with any certainty that one group of students performed significantly better than the other group. In addition, due to the smaller number of student responses to the ADT (students were not required to complete the ADT, and so not everyone did) and the small number of questions related to the video, we are also unable to state within the $\alpha=0.05$ level that the web students performed significantly better than the F2F students on these questions.

4. DISCUSSION

In general, watching the videos was strongly correlated with better student performance on relevant examination questions, such that students had a 95% chance of performing between 16% and 77% better on relevant exam questions (Sec. 3.1). Since all of the students watched at least some of the videos, motivation or talent cannot be the sole determinant of performance.

There are several reasons that we suspect why the videos were as effective as they were. Humor and an underlying theme were also introduced into the videos to keep the students attentive while watching the videos. Humor has been shown to be an effective tool in increasing student attention and performance in college courses (Ziv 1988; Garner 2006). We also kept the videos brief, most only 3–5 min in length, so as not to exceed the students' attention spans. The videos reinforced material covered within the lecture notes and provided the students with an alternative method of instruction.

Precisely which videos were most responsible for the observed improvement? Only video 3 provides a clear rejection of the null hypothesis: by watching this video, students were 9.8 times more likely to respond correctly to examination questions related to this video. It is worth examining this video and the related questions in more detail. In this demonstration, a reproduction of Galileo's experiment, the first author drops two balls of unequal weight off the edge of an elevated hallway onto the floor below. Both objects strike his assistant in the head simultaneously, thus illustrating that in the absence of air resistance, all objects fall at the same rate. The examination question posed to the students is as follows (* indicates the correct answer):

> Prof. Miller drops two objects from the edge of a balcony. They both hit the ground at the same time because
> 1. they have the same mass
> 2. they have the same shape
> 3. all objects fall at the same rate, independent of their shape *
> 4. they have the same density

Students who did not watch this video would have encountered this concept in the lecture notes, which contained a static picture of Galileo dropping two objects off of the leaning tower of Pisa. Given the question's direct reference to the demonstration and to the first author's role in performing it as opposed to Galileo, we suspect students had an easy time recalling the conclusions of the video.

While no other video provides clear evidence for the rejection of the null hypothesis, videos 4 and 16 were effective at the $\alpha=0.10$ level (e.g., less significant than the $\alpha=0.05$ level). Video 4 demonstrated Newton's first law of motion, the law of inertia. In this video, the first author pulls a tablecloth out from underneath a place setting without the place setting moving. The associated exam question asked the students which physics principle is demonstrated by pulling a tablecloth out from underneath a place setting. Like the question regarding Galileo's experiment, this question directly references the demonstration performed in the video. Students who did not watch the video could have read about the law of inertia in the lesson notes, but no specific example of an object at rest staying at rest was provided.

Video 16 demonstrated the bias in the apparent variety of stars observed in the sky vs the actual distribution of stellar types. This was demonstrated in the video by covering the first author's van with Christmas lights. When far away, the lights were too dim to be observed, yet the van's bright headlights were easily viewable. It was only as the van pulled closer that the presence of the dimmer, yet more numerous Christmas lights became apparent. The associated question asked students to identify the most common type of star by number in our galaxy. Unlike the previous two examples, this question does not directly refer to the demonstration. Students who did not watch the video could have read about this selection effect in the notes. The notes were accompanied by two Hertzsprung-Russell (HR) diagrams: one plotting the positions of the brightest stars as observed from Earth, the other plotting the positions of the nearest stars to Earth. While the second HR diagram clearly shows that the nearest stars are low-mass "dim" main-sequence stars, students need to read the accompanying text to understand why this sample is not biased by any selection effect. Based on this, we suggest that the reason why students who watched the videos may have performed better on this question than those who did not is due to the fact that video demonstration was more visual and memorable than the lesson notes. A number of studies (Mayer 2003; Felder and Silverman 1988) show that more students are visual learners than verbal learners, and so the video demonstration was more aligned toward their learning style.

Videos 18 and 19 were possibly ineffective and may have confused students. Video 18 was a demonstration of a spiral density wave moving through a galaxy, much like audience members at a sporting event may sometimes do "the wave" through a crowd. The video also demonstrated how dim red stars move out of a spiral arm before dying, while luminous blue stars do not. Star formation was represented by students holding up different sheets of colored paper as they walked past the "spiral wave" (represented by a slower moving group of students). The students with blue pieces of paper ducked out of line before passing the spiral wave, while students with red pieces of paper continued passed. The associated question asked students why red, K and M main-sequence stars were not good spiral tracers. It could be that while this video was visually appealing, it may have been difficult for students to apply the demonstration to star formation within spiral arms. The lesson notes included an animation that demonstrated the same principle, but occurring within a spiral galaxy, and so may have demonstrated this principle more clearly than the video.

Video 19 was a demonstration of the expansion of the universe. A balloon with a number of dots taped to it was blown up. As the balloon expanded, the dots all moved away from one another. The students who did not watch the video would have encountered this concept in the lesson notes as an animation of galaxies moving away from one another on a two-dimensional screen. The associated question asked students about the location of the center of the universe. The lesson animation demonstrated the expansion of the universe from two locations, showing that there is no preferential "center." The video demonstration focused on our view from our Galaxy. This may have caused some confusion for the students, resulting in more students choosing an incorrect answer.

The confidence limits of our data are rather substantial due to the fact that within the online course almost all of the students watched the videos. The videos were not mandatory and cover any material found elsewhere in the course, yet almost all of the online students chose to watch the videos. While we are pleased that the students elected to watch the videos, small values of n_{10} and n_{11} led to a large standard error. The strength of these statistics would be greatly boosted by a larger population of students who did not watch some of the individual videos.

One of the greatest challenges associated with analyzing these data is the imprecise nature of the student survey responses. By distributing the videos through multiple media outlets, we lost the ability to precisely track student participation and had to rely upon their responses to survey questions instead. Dishonest selections (intentionally or otherwise) on these survey questions would obviously skew our results. Future examinations on the efficacy of these videos should be based upon student-identified clicks to the videos. These data could be coupled with an identical survey question ("Select the video(s) you watched before taking this exam") to measure the efficacy of such a survey.

5. CONCLUSIONS

We find that the video demonstrations do, in general, provide online students with a statistically significant educational benefit. When comparing the F2F students with the online students on both examination questions unrelated to the videos and the ADT post-test, we find that the F2F students performed significantly better than the online students. When asked questions related to topics covered by the videos, the online students perform as well as the F2F students. Online students who watched the videos had a 95% chance of performing between 16% and 77% higher on the relevant exam questions.

However, we find that only one video is clearly helpful. We ascribe a number of reasons to why more individual videos are not being indicated as clearly helpful. First, our sample compares two groups of students: those in the online course who watched the videos and those who did not. Unfortunately, for our calculations, the population of the latter group was rather small, causing large confidence limits in our calculations. Future studies should include a comparison between two groups roughly equal in size, where one is shown the videos while the other is not. Second, we were unable to track actual observations of the videos and so had to rely solely on student feedback. Whether intentionally or otherwise, students may have incorrectly reported which videos they did or did not watch. Third, the questions used in the comparison were simply questions from the exams. They were not standardized questions that have been field tested and proven to be excellent indicators of student knowledge. In terms of the ADT results, only three out of the 21 questions on the ADT overlap with topics covered by the videos. Unfortunately, these three questions do not provide enough data to allow us to state with any significance whether or not the students who watched the videos performed better than the students who did not. So while the ADT in general is a good indicator of the disparity between the F2F course and the online course, it is not indicative of the effectiveness of the videos. Future studies should include a closer match between video topics and field-tested questions, such as the Test of Astronomy Standards (Slater 2009) or any number of concept inventory tests. In addition, to help make the videos even more engaging, a set of workbook activities or something analogous should accompany them to help students reinforce and apply the material they just observed.

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