# The Effects of Video-Based Pre-Lab Instruction on College Students' Attitudes and Achievement in the Digital Era

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Abstract

This study examines the effectiveness of pre-laboratory presentations in an undergraduate general chemistry laboratory using two different modes of delivery: a traditional lecture versus an in-class video presentation. It was anticipated that implementation of videos could result in improved laboratory efficiency, safety, and necessary technical skills for the students. Thus, the purpose of this study was to examine this hypothesis by comparing laboratory quiz scores and completion times of students who received their pre-laboratory instruction in a traditional lecture versus in-class video format. The results of this study provide new insight into the benefits of using technology for delivery of pre-laboratory instruction and offer suggestions for considerations when implementing technological tools (such as videos) into laboratory instruction.

Keywords: undergraduate education, chemistry, pre-laboratory instruction, instructional technology, chemical education

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## Introduction

Undergraduate chemistry courses have received a great deal of attention in research due to their important role in chemical education and the diverse body of students they service (Bruck, Towns, & Bretz, 2010; Chaytor, Mughalaq, & Butler, 2017; Reid & Shah, 20007). Laboratory courses can be particularly challenging; students may merely follow a step-by-step process to complete the laboratory activities without any substantial understanding of the purpose for their steps or how those actions connect to the theory learned within the corresponding chemistry course (Mohrig, 2004; Seery, 2013). Add to this the needs of many colleges and universities to offer a large quantity of laboratory sections. As a consequence, laboratory sections are frequently taught by part-time instructors who often are not the instructor of the lecture component of the course. This can result in inconsistencies across multiple sections and instructors (Chaytor et al., 2017;

Nadelson, Scaggs, Sheffield, & Mcdougal, 2014). In an attempt to address this issue at our university, we developed videos as an alternate mode of delivery of pre-laboratory instruction.

**Pre-Laboratory Instruction to Improve Attitudes and Reduce Cognitive Load**

Laboratory experiences are critical both in students building a strong foundation in science principles and in developing positive attitudes and motivation for learning science, making it imperative to consider ways to improve the laboratory experience (Freedman, 1997; Lyle & Robinson, 2002; Rollnick, Zwane, Staskun, Lotz, & Green, 2010). While students' motivations to learn and attitudes toward learning are important across all disciplines (Schunk, Pintrich, & Meece, 2014), reports of declining motivation to learn science (George, 2007; Vedder-Weiss & Fortus, 2011) make it particularly critical to consider ways of improving students' attitudes toward science. Furthermore, the hands-on and practical experiences offered by a laboratory setting can positively impact students' attitudes toward science (Freeman, 1997; Vedder-Weiss & Fortus, 2011). Thus, as we consider modes of delivery of laboratory instruction within science courses, it is important to examine effects on students' attitudes.

Cognitive load theory acknowledges that individuals may have difficulty processing or learning new information when placed in a learning environment that requires them to use all their working (or short-term) memory (Baddeley & Hitch, 1974; de Jong, 2010; Kirschner, 2002; Seery & Donnelly, 2012). Reid and Shah (2007) connected cognitive load theory to the undergraduate chemistry laboratory experience by pointing to the many components of this experience that compete for students' working memory, including written laboratory manual instructions, theoretical ideas from lecture, new and unfamiliar laboratory equipment, and time constraints. The idea driving much of the research on pre-laboratory preparation is that engaging students in activities that allow them to process information prior to performing the actual laboratory experiment will reduce anxiety, increase confidence, and free up working memory to engage more meaningfully, and therefore have a richer learning experience, inside the laboratory (Limniou, Papadopoulos, & Whitehead, 2009; O'Brien & Cameron, 2008; Schmid & Yeung, 2005). Furthermore, because research supports the existence of separate visuospatial and phonological subsystems of working memory (Baddely & Hitch, 1974; de Jong, 2010), much of the attention on pre-laboratory instruction has focused on the use of videos or other multi-media presentations of these ideas.

**Use of Multi-Media in Pre-Laboratory Instruction**

Videos have long been recognized as an effective source of communication of laboratory skills (Kempa & Palmer, 1974; Meloan, 1971). Kempa and Palmer (1974) showed that videos were superior to written instruction in teaching students manipulative laboratory skills. More recently, attention has turned to a flipped-classroom model in which students complete interactive tutorials, which often include a video component, prior to the laboratory session (Chaytor et al., 2017; Burewicz & Miranowicz, 2006;, Canal, et al., 2016; Jolley, Wilson, Kelso, O'Brien, & Mason, 2016; Koehler & Orvis, 2003; McKelvy, 2000). Burewicz and Miranowicz (2006) compared three approaches to pre-laboratory instruction: traditional written instruction, video instruction, and an interactive video-based computer program. Although it took students more time to complete the video and interactive computer program pre-laboratory instruction, the students who received these modes of pre-laboratory instruction took less time to complete the actual experiments. Furthermore, while all three modes of delivery led to equal outcomes in terms of theoretical work on the labs, the students who received either the video or interactive computer instruction exhibited better manipulative skills, likely because of the video demonstrations of these techniques. Students receiving the interactive computer instruction demonstrated a further advantage when it came to using measurement software (Burewicz & Miranowicz, 2006).

Jolley and colleagues (2016) investigated the effectiveness of online pre-laboratory exercises in a second–year analytical chemistry course in Australia. Students were required to complete a pre-laboratory quiz with at least 80% accuracy at least 24 hours before attending the laboratory course. Pre-laboratory videos and exercises were created to aid students in passing the quiz, although their viewing was not required. Results showed that these pre-laboratory activities led to self-reports that students spent more time in preparation for the lab than they had in traditional laboratory classes, and that students showed an increase in positive attitudes towards, although not necessarily an increase in performance on, their laboratory reports.

Across the many studies that have investigated the use of multimedia modes of delivery of pre-laboratory instruction, there is consensus that moving away from traditional pre-laboratory instruction of solely written materials and verbal instruction yields benefits to students, including decreased time for laboratory completion (Nadelson et al., 2014), better manipulation skills (Kempa & Palmer, 1974; Burewicz & Miranowicz, 2006), improved procedural and conceptual knowledge (Nadelson et al., 2014), increased time spent preparing and improved student perceptions of preparation for laboratories (Jolley et al., 2016). Despite the consensus that alternative approaches to pre-laboratory instruction are beneficial, research has not identified why these approaches lead to improvements nor fleshed out the components of the pre-laboratory activities which contribute to the noted improvements. Jolley and colleagues (2016) call for more research '[…] in both the technologies and how we can quantify if better analytical results were achieved, and if the student experience is significantly improved' (p. 1861).

One interesting question is the role of the videos themselves, especially in light of the increased accessibility of videos for learning purposes through internet resources (Berk, 2009; Brown, 2000; Tucker & Courts, 2010). While much of the recent research examines pre-laboratory exercises which include a video component, the role of the video itself in student achievement is unclear due to additional implementation factors such as a flipped-classroom environment or accompanying interactive web-based activities. Those studies which have looked strictly at the benefit of videos as a mode of delivery pre-date the wide accessibility of videos as learning tools through internet resources. Today's college students have grown up in the digital age, surrounded by learning resources, such as YouTube and Khan Academy, which are available at the touch of a screen. Despite the great potential of these learning resources, issues of equity related to Internet access have been a concern for many years (Norris, 2001; vanDijk, 2005, 2006). As Tsetsi and Rains (2017) point out, smartphones have both bridged and extended these gaps. Another consideration is that while students are more technologically savvy than ever before, research has shown they may also be more accustomed to multi-tasking and potentially distractible (Brown, 2000; Junco, 2012). Prior to the internet, videos in instruction were seen as a novelty that naturally attracted students' attention and kept their interest (Kempa & Palmer, 1974; Meloan, 1971). But in a world where YouTube videos on any imaginable topic are streamed free in an instant, it is reasonable to assume that students may approach watching videos during class time differently than they did in previous generations. Thus, one reason for the current study is to examine the effectiveness of videos as a mode of pre-laboratory instruction in the present digital age. A second reason for the current study is that we aim to compare the effectiveness of the pre-laboratory video instruction with that of a traditional lecture, our alternative format of instruction.

**Our Study**

Recognizing that much has changed regarding both videos as multimedia learning tools and their roles in students' lives, we aim to examine the modern benefits of using videos as a mode of delivery of in-class, pre-laboratory instruction as compared to a traditional lecture-based mode of delivery. Although increasing consistency across laboratory sections motivated our pedagogical decision to use videos, the primary goal of this research study is to measure the effectiveness of pre-laboratory video instruction. In particular, our study examines if in-class instructional videos (as a means to improve consistency across multiple sections and instructors) can effectively (as measured by students' laboratory quiz scores and laboratory completion times) deliver pre-laboratory instruction. Note that this study does not examine the extent to which the in-class instructional videos promoted consistency across sections, but rather focuses on their effectiveness. We also hope to add to the existing literature by examining whether particular sub-groups of students (e.g., based on gender, year in school, native language) benefit more or less from pre-laboratory instruction in a particular mode of delivery. This question is not addressed by past research on pre-laboratory instruction and is pertinent as our undergraduate chemistry courses become increasingly diverse. Thus, the questions guiding our research include:

(1) Do students in an introductory chemistry course who receive pre-laboratory instruction via an in-class video outperform their peers who receive pre-laboratory instruction via an in-class lecture on their pre-laboratory quizzes?
(2) Do the performance results vary depending on particular sub-characteristics such as gender, year in school, or native language?
(3) Do students in an introductory chemistry course who receive pre-laboratory instruction via an in-class video complete their laboratory experiments in less time than their peers who receive pre-laboratory instruction via an in-class lecture?
(4) What are students' attitudes toward laboratories?
(5) Do students' attitudes toward laboratories vary based on whether they received pre-laboratory instruction in a video or lecture format?

**Development of Videos**

The pre-laboratory videos were developed in the spring of 2015 in an effort to bring more consistency to pre-laboratory instruction across sections. These scripts were developed by the general chemistry laboratory coordinator, who has 23 years of experience in this role. The video scripts were designed to include material that the laboratory coordinator felt addressed the technique being performed and the appropriate safety instructions for that particular chemistry experiment. Two undergraduate chemistry majors served as the "actors" for the videos, demonstrating laboratory techniques and providing the narrative of the video scripts.

In total, 11 pre-laboratory videos were created; one for each class in which students performed an in-class laboratory. Summaries of the laboratories and the content of the pre-laboratory videos are provided in Table 1.

Table 1

*Laboratories with Associated Videos and Quizzes*

| Laboratory Title | Video(s) and Time | Associated Main Video Topics |
|---|---|---|
| Introduction to Chemistry Techniques (Parts I, II, and III) | Video 1 (5min 9 sec) | Proper use of laboratory equipment (i.e.: analytical and top loader balances, graduated cylinder for volume, use of a pipet); Determine the volume of an object (displacement and measurements) and ultimately the density of an unknown object |
| | Video 2 (7min 37 sec) | Introduction to concept of concentration along with technique for dilutions; Proper use of a volumetric flask;<br>Proper use of a spectrometer; Introduction to spectroscopy and Beer's Law |
| Properties of Hydrates | Video 3 (4 min 44 sec) | Introduction to and analysis of hydrated compounds; Proper use of a Bunsen burner |
| Rust and Other Oxides | Video 4 (3 min 16 sec) | Introduction to concept of an oxide compound; Determine the empirical formula of an iron oxide; Proper use of Bunsen burner |
| Ionic Reactions in Aqueous Solution | Video 5 (3 min 15 sec) | Introduction to precipitates and precipitation reactions;<br>Proper observations of precipitation reactions; Introduction to coordination compounds; Procedure to form crystals and observe how they should appear upon formation; Proper use of suction filtration; How to clean, dry and store crystals |
| Analysis of Commercial Antacids Containing Calcium Carbonate (Parts I and II) | Video 6 - Part I (4 min 51 sec) | Introduction to acid-base chemistry and titrations; How to prepare an NaOH solution and standardize the solution with a primary standard; Proper preparation and use of a buret for titrating an acid with a base. |
| | Video 7 – Part II (2 min 28 sec) | Introduction to concept of a back titration; Proper way to heat a solution and rid said solution of carbon dioxide; Different indicators in an acid-base titration have different color changes at the end point. |
| Coordination Compounds with Copper(II) (Part IIA and IIB, IIC) | Video 8 – Part IIA and IIB (7 min 7 sec) | Introduction to analysis of coordination compound crystals made two weeks prior through redox titration; How to standardize a $KMnO_4$ solution with $Na_2C_2O_4$; How to properly |

| | | |
|---|---|---|
| | | heat a solution; How to use standardized $KMnO_4$ to analyze crystals for mass percentage of oxalate ion. |
| | Video 9 – Part IIC (2 min 54 sec) | Reintroduction to spectroscopy; How to determine the mass percentage of copper (II) in crystals by forming a complex of copper (II) with $NH_3$ and then using spectroscopy. |
| Molar Mass and the Ideal Gas Law | Video 10 (4 min 6 sec) | Introduction to concept of gases and the ideal gas law; How to determine the amount of gas produced from a reaction of a metal with HCl through volume displacement in a buret. |
| Calorimetry and Hess's Law | Video 11 (2 min 44 sec) | Introduction to calorimetry; Proper use of a coffee cup calorimeter; How to determine the enthalpy of a reaction of an acid and base by using Logger Pro to find the final temperature through extrapolation to the *y*-intercept in a graph of temperature vs time. |

## Methods

This study took place during the fall 2015 and spring 2016 semesters at a primarily undergraduate college in the North-eastern United States. Students enrolled in Chemistry 111 (Chem 111) during these two semesters were the targeted participants of the study. Chem 111 is a one-credit laboratory course designed to be taken concurrently with a three-credit lecture course, Chemistry 110 (Chem 110). According to the official course description, Chem 110 is the first-semester of a comprehensive, two-semester course in general chemistry which introduces students to basic principles of chemistry. These courses are typically taken by students majoring in science, technology, engineering, or math (STEM) disciplines. Students generally do not have the same instructor for Chem110 and 111, and many sections of Chem 111 are taught by part-time faculty members.

In both the fall 2015 and spring 2016 semesters, each section of Chem 111 was randomly designated as either a lecture or video section, with roughly equal numbers of sections with each designation. When one instructor had multiple sections, these were distributed as evenly as possible between lecture and video designations. At the start of each semester, the laboratory coordinator visited each section of Chem 111 and explained the purpose of the research project and obtained students' informed consent to participate in the study. Note that agreeing (or not) to participate in the research did not have any impact on students' experiences or grades during the semester, but it did determine if their results were recorded and reported for the purpose of our research. In the fall 2015 semester, 370 students across 16 sections of Chemistry 111 consented to participate in the study. In the spring 2016 semester, 236 students across 11 sections participated.

Over the course of each semester, the following tools were administered and corresponding data recorded for each consenting student: (1) a demographic survey (to collect basic demographic information), (2) 11 pre-laboratory quizzes (individual student scores were recorded), (3) 11 laboratory assignments (individual student completion times were recorded), and (4) a Likert-scale post-survey regarding students' attitudes toward and perceptions of preparedness for the laboratory component (fall 2015 semester only). Additional details regarding these four measures are provided below.

### Demographic Survey

The demographic survey was administered on the first day of class. This seven-question survey asked students to identify their gender, academic year, intended major, first language, and chemistry background (how many previous courses, whether they took a course in high school, and if they had a laboratory component in previous courses). Responses to the survey items were recorded to provide demographic information linked to each student.

### Quiz Scores and Laboratory Completion Times

During each of the 11 weeks in which students completed a laboratory experiment during class time, class began with pre-laboratory instruction delivered either by the laboratory instructor or via the pre-laboratory videos. For both approaches, the content of the pre-laboratory instruction was primarily the same (see the video summaries above). Immediately following the pre-laboratory instruction, the students were asked to independently complete a five-question, open-response quiz. The quizzes were the same across all sections and focused on key points from the pre-laboratory instruction. Each question was scored as correct or incorrect, and each student received a quiz score based on the number of questions answered correctly. This score was strictly for research purposes and did not contribute to students' overall course grades. After submitting the quiz, each student signed-in to record their start time and began to work on the lab. When students completed the lab, they signed-out and indicated their completion time. At the completion of each laboratory, a quiz score (total number correct) and total laboratory completion time (calculated as elapsed time using the start and ending times) were recorded for each student.

### Post-Survey

The post-survey was administered on the last day of class in the fall 2015 semester only. This was a nine-item Likert scale survey intended to provide feedback regarding students' attitudes about their laboratory experiences, in general, and the pre-laboratory instruction, in particular. The post-survey extended the concept of perceived usefulness of and preparedness for laboratories as presented in prior research (Jolley et al., 2016) by including specific statements to address elements of preparation (2,6,7,8) and utility (1,4,7,8). To address the broader issue of helping students develop positive attitudes toward laboratory sciences, two items were included that addressed students' enjoyment of the experiences (3,9). One item (5) was also included to gauge students' perception of the usefulness of their teacher. Students were asked to respond to each statement (see Table 2) with one of five responses: Strongly Disagree, Disagree, Neutral, Agree, or Strongly Agree. Students' responses to the post-survey were recorded.

Table 2

*Post-Survey Likert-Scale Statements*

| Number | Statement |
|---|---|
| 1 | The pre-lab safety information was important for my completion of the labs. |
| 2 | Expectations for the labs were well communicated prior to beginning an experiment. |
| 3 | I enjoyed working in the laboratory. |
| 4 | My experiences in the laboratory helped to reinforce the concepts from Chem 110. |
| 5 | My laboratory instructor was helpful. |
| 6 | I am confident in my ability to work in a laboratory setting. |
| 7 | I understand basic laboratory procedures and safety protocols. |
| 8 | I understand how to use laboratory tools and equipment. |
| 9 | I hope to have more experiences working in a laboratory. |

**Results**

A total of 606 students consented to participate in the study, 370 students in the fall semester (from 16 sections of the course) and 236 students in the spring semester (from 11 sections of the course). The students were predominantly freshmen, more than two-thirds were male (this is consistent with the student population at the college, in general), most had taken at least one chemistry course in high-school, and the majority were native English speakers. A summary of the self-reported characteristics of the population is provided in Table 3.

Table 3

*Participant Demographics as Self-Reported on the Demographic Survey*

| | Fall 2015 | | Spring 2016 | | Combined | |
|---|---|---|---|---|---|---|
| Demographic | n | % | n | % | n | % |
| Total | 370 | 100 | 236 | 100 | 606 | 100 |
| Male | 264 | 71 | 165 | 70 | 429 | 71 |
| Female | 105 | 28 | 71 | 30 | 176 | 29 |
| Freshmen | 298 | 81 | 174 | 73 | 472 | 78 |
| Non-Freshmen | 70 | 19 | 63 | 27 | 133 | 22 |
| High School Chemistry | 357 | 96 | 225 | 95 | 582 | 96 |
| No High School Chemistry | 12 | 3 | 10 | 4 | 22 | 4 |
| Native English Speaker | 330 | 89 | 200 | 84 | 530 | 87 |
| Non-Native English Speaker | 40 | 11 | 37 | 16 | 77 | 13 |

We begin by reporting results related to students' quiz performance and laboratory completion times for the traditional lecture versus pre-laboratory video classes. These results are followed by students' responses to the post-survey related to their experiences with the pre-laboratory videos versus lectures.

## Quiz Results

We analyzed the scores for the 11 quizzes taken. The goal of the analysis was to see on average if the scores in the video group were significantly greater than those in the lecture group. The analysis was conducted on the quiz scores for both the fall 2015 and spring 2016 semesters. We did this by considering the students over all sections within each group (lecture or video) as a representative independent random sample from the population of all similar students taking Chem 111 under either the lecture or video format, respectively. The scores from all sections within each group (lecture or video) were combined and treated as a single sample. Particular students with missing values for a given quiz in either group were deleted from that sample. Also, any students who did not give consent to have their scores included in the study, or any students who dropped the class during the semester, were not part of the sample. The overall sample size for each set of quiz scores was 312 in the fall semester and 177 in the spring semester. This provides a sufficient sample size to assume approximate normality of the sample means.

The mean quiz scores for students in the pre-laboratory lecture versus video sections are provided in Figure 1. The results for the fall and spring semesters show strikingly similar patterns: not only do the average scores follow similar trends across semesters (e.g., low scores on quiz 5 and 11, high scores on quiz 3 and 10), but the relationships between how the lecture and video groups performed also show trends across the semesters. In both semesters, the pre-laboratory video sections began with lower average scores on the first two (fall) or three (spring) quizzes, followed by consistently higher average scores for the pre-laboratory video sections on the remaining quizzes.

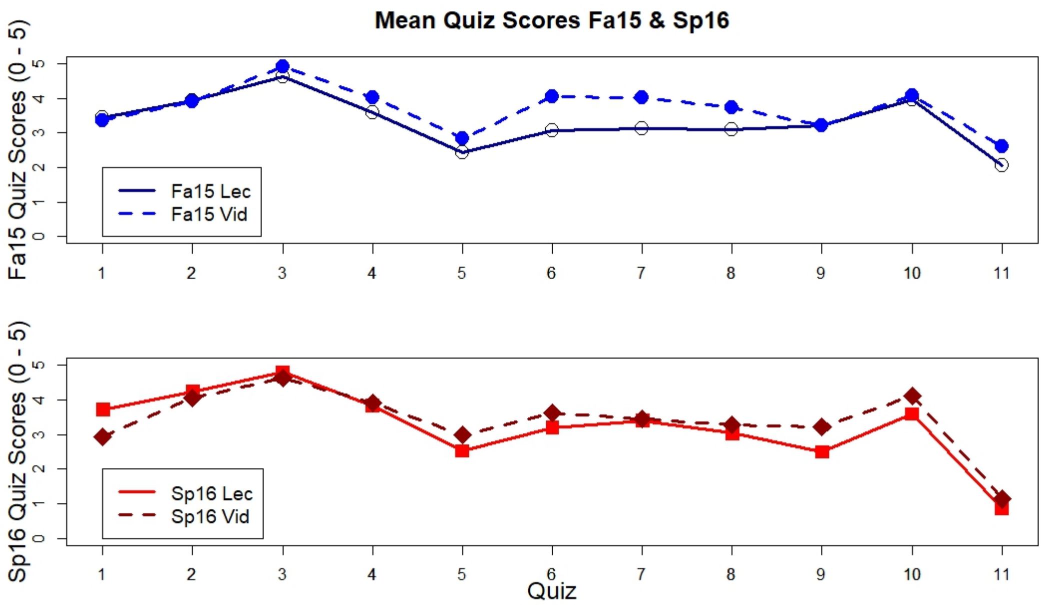


Figure 1. Comparison of mean scores based on pre-laboratory mode of delivery. Over both semesters, the pre-laboratory video sections show higher mean averages beginning with quiz 3 or 4.

A two-sample t-test using the combined quiz scores for each group was performed on each of the 11 quizzes to test the hypothesis that there is no difference in the overall mean scores $H_0 : \mu_{Lec}^{(i)} = \mu_{vid}^{(i)}$ versus the hypothesis $H_a : \mu_{Lec}^{(i)} < \mu_{vid}^{(i)}$ that the overall mean scores were higher in the video group, where $\mu_{Lec}^{(i)}$ and $\mu_{vid}^{(i)}$ represent the population mean quiz score of the lecture and video groups, respectively, for quiz $i = 1,\ldots,11$. This was completed for both the fall 2015 and spring 2016 semesters. The computed p-values of the two-sample t-tests for both semesters are shown in Table 4 and provide additional insight into the differences seen in Figure 1. As a reference, the p-values in Table 4 denoted with an asterisk * indicate statistical significance of the alternative hypothesis $H_a^{(i)}$ at the $\alpha = 0.05 \div 11 = 0.0045$ level of significance, where a Bonferroni correction is used to adjust for the 11 separate hypothesis tests. The dagger †indicates a p-value greater than 1-0.0045 = 0.9955, which would imply a significant result in favor of the opposite alternative $H_a^{(i)}: \mu_{Lec}^{(i)} > \mu_{Vid}^{(i)}$, i.e. that the mean score in the lecture group is greater than the video group for quiz *i.* We note that our choice of $\alpha$ here is arbitrary and the strength of the evidence may still ultimately be determined by the reader. Effect size was calculated using the Cohen's *d* statistic (Cohen, 1988). In our discussion below we use the rough scale given by Cohen (1988) to interpret the effect size as *small = 0.*20, *moderate = 0.*50, and *large = 0.*80. The results show strong evidence in favor of the video sections scoring significantly higher on quizzes 3-8 with small p-values and mostly moderate to large effect sizes. Quiz 11 shows strong statistical evidence in favor of the video group scoring higher, but has a smaller effect size. From Figure 1, the difference in means seems to be greater for quiz 11 than that of quizzes 3 or 4 which had larger effect sizes. When looking at the distribution of scores for quiz 11, we saw there were a few students who scored "0" in each group. This may have inflated the standard deviation and hence lowered the effect size. Results for the spring semester show strong evidence in favor of our alternative hypothesis on quizzes 5, 6, 9, and 10, with small p-values and moderate to large effect sizes. There is weaker evidence for quizzes 8 and 11. As we saw in Figure 1, both semesters began with lower mean quiz scores in the video group, particularly for quizzes 1 and 2 in the fall and quizzes 1, 2, and 3 in the spring. The spring quiz 1, with p>0.999 and effect size 0.613, seems to be the only significant result. The spring quizzes 2 and 3 have somewhat larger p-values but smaller effect sizes. For the fall quizzes 1 and 2, there is not strong evidence at all that the larger mean lecture quiz score is significant.

Table 4

*Results of Two Sample T-Tests on Quiz Scores*

| | Fall 2015 | | Spring 2016 | |
|---|---|---|---|---|
| Quiz | p-value | Effect Size | p-value | Effect Size |
| Q1 | 0.712 | 0.063 | >0.999† | 0.613 |
| Q2 | 0.608 | 0.031 | 0.959 | 0.264 |
| Q3 | <0.001* | 0.660 | 0.969 | 0.291 |
| Q4 | <0.001* | 0.571 | 0.260 | 0.097 |
| Q5 | <0.001* | 0.400 | 0.002* | 0.447 |
| Q6 | <0.001* | 1.016 | 0.002* | 0.435 |
| Q7 | <0.001* | 0.847 | 0.339 | 0.063 |
| Q8 | <0.001* | 0.647 | 0.057 | 0.246 |
| Q9 | 0.446 | 0.015 | <0.001* | 0.661 |
| Q10 | 0.117 | 0.135 | <0.001* | 0.639 |
| Q11 | 0.001* | 0.345 | 0.044 | 0.264 |

*Notes. We performed a left-tailed t-test on mean scores for each quiz;*

$H_0: \mu_{Lec} = \mu_{Vid}$ *vs.* $H_0: \mu_{Lec} < \mu_{Vid}$. *Used Bonferroni correction to get significance level* $\alpha = .05 \div 11 = .0045$. *Effect size computed using Cohen's d.*
** p < .0045. † p > .9955 (equivalent to p < .0045, right-tailed).*

To determine if higher quiz scores for the video group could be attributed to increased scores for specific sub-populations (e.g., male students), trends of quiz scores for sub-populations based on gender, year in school, and English as first language were examined. The results for fall 2015 and spring 2016 semesters showed no significant differences in the overall patterns by semester. Therefore, the results for fall 2015 and spring 2016 are combined in the figures below. The resulting quiz scores over both semesters for freshmen and non-freshmen (Figure 2), males and females (Figure 3), and English and non-English as first language (Figure 4) students all show trends similar to the overall results provided in Figure 1. The only slight exception is a dip in the scores of the non-native English speakers in the video sections on quiz 9. Overall, this additional analysis suggests that students benefitted similarly from the pre-laboratory videos regardless of their gender, year in school, or native language.

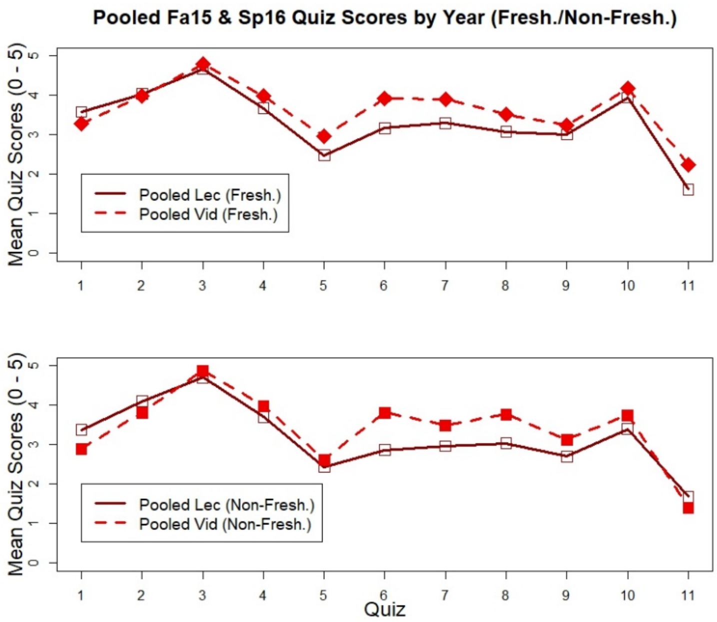


Figure 2. Comparison of mean scores for freshmen and non-freshmen based on pre-laboratory mode of delivery. The trends for both freshmen and non-freshmen follow the trends for the whole population.

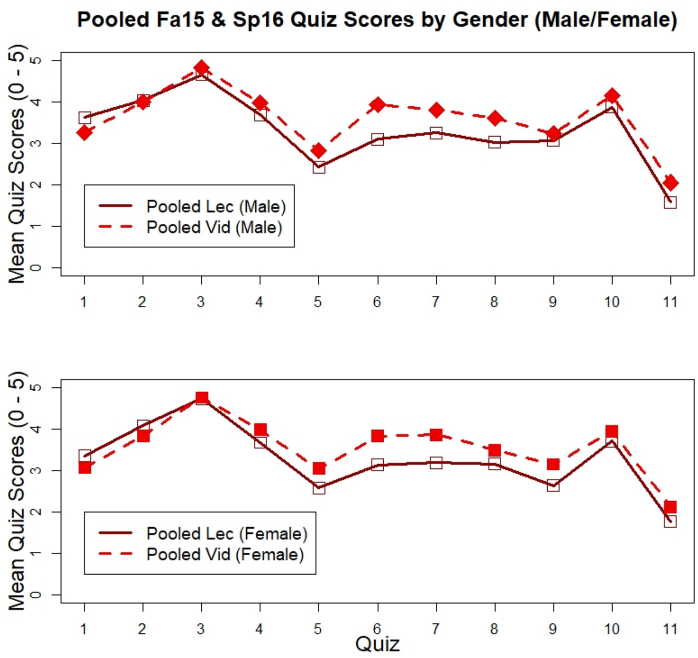


Figure 3. Comparison of mean scores for male and female students based on pre-laboratory mode of delivery. The trends for both male and female students follow the trends for the whole population.

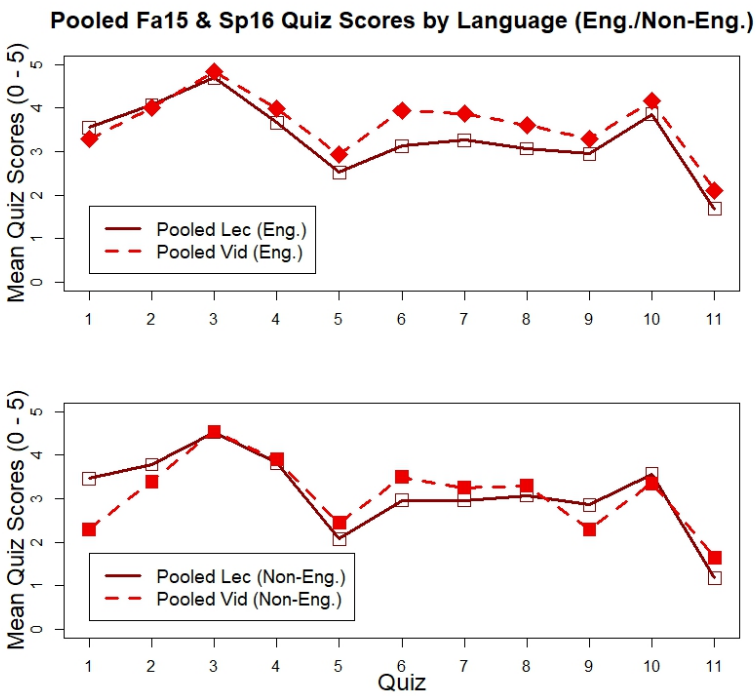


Figure 4. Comparison of mean scores for native and non-native English speakers based on pre-laboratory mode of delivery. The trends for both native and non-native English speakers primarily follow the trends for the whole population.

**Laboratory Completion Times**

Since past research has found that pre-laboratory video instruction can decrease the amount of time required to complete a lab (Burewicz & Miranowicz, 2006; Nadelson et al., 2014), we completed additional analyses to compare the total laboratory completion times for students enrolled in the video versus lecture sections. The trends in the data (see Figure 5) show relatively similar completion times for most of the quizzes regardless of which mode of instruction students received.

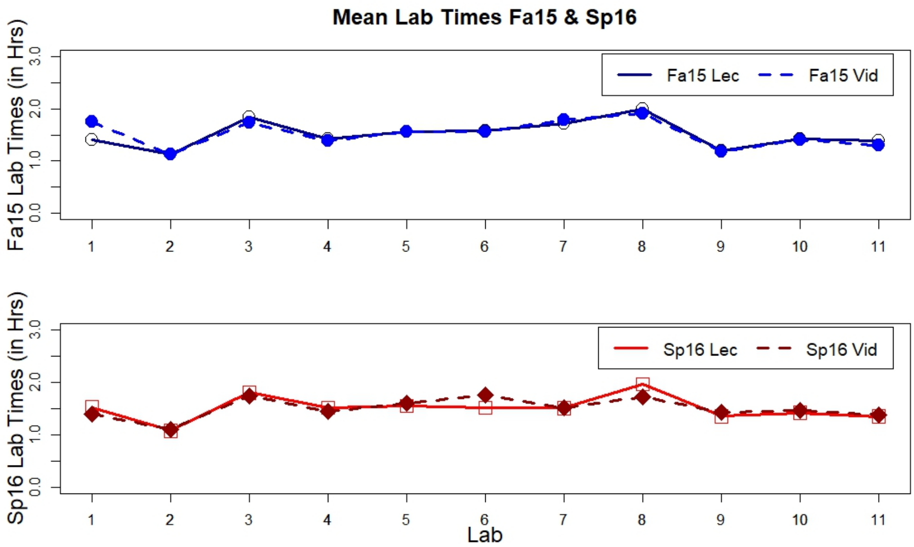


Figure 5. Comparison of mean laboratory completion times based on pre-laboratory mode of delivery.

An analysis was conducted to determine if the influence of the pre-laboratory videos allowed students to generally complete the labs in a shorter period of time than the lecture group. To investigate this, a two-sample t-test for each of the 11 labs was performed using the combined lab completion times for each group to test the hypothesis of no difference in overall mean completion time $H_0^{(j)}: \theta_{Vid}^{(j)} = \theta_{Lec}^{(j)}$ versus the hypothesis $H_a^{(j)}: \theta_{Vid}^{(j)} < \theta_{Lec}^{(j)}$ that the mean completion times in the video group were lower. Here $\theta_{Vid}^{(j)}$ and $\theta_{Lec}^{(j)}$ represent the population mean completion times for the video and lecture groups, respectively, for lab $j = 1,\ldots,11$.

Table 5 gives the p-values and effect sizes obtained for each semester. Again, for reference, a single asterisk indicates a statistically significant result of the mean completion time for the video group being less than the mean completion time for the lecture group at the $\alpha = 0.05 \div 11 = 0.0045$ level of significance, using a Bonferroni correction. A dagger indicates a statistically significant result in favor of an alternative hypothesis in the opposite direction, $H_a: \theta_{Vid} > \theta_{Lec}$. That is, that the mean completion time for the lecture group was significantly less than the mean completion time for the video group at the given level of significance.

The results in Table 5 show strong statistical evidence that the mean completion time in the fall 2015 the video group is lower for lab 11, and possibly lab 3 although the effect sizes are on the small side. The strongest evidence in the spring 2016 times was for lab 8, but the effect size is only moderate. In contrast, we see strong statistical evidence in favor of the mean completion time of the lecture group being lower for lab 1 in fall 2015 and for lab 6 in spring 2016, but the effect sizes are moderate. Apart from these, and considering what we see in Figure 5, there is no clear trend of one group consistently having lower laboratory completion times than another.

Table 5

*Results of Two Sample T-Tests on Lab Completion Times*

| | Fall 2015 | | Spring 2016 | |
|---|---|---|---|---|
| Lab | p-value | Effect Size | p-value | Effect Size |
| Lab 1 | >0.999† | 0.472 | 0.024 | 0.316 |
| Lab 2 | 0.525 | 0.007 | 0.703 | 0.081 |
| Lab 3 | 0.006 | 0.287 | 0.091 | 0.203 |
| Lab 4 | 0.243 | 0.079 | 0.027 | 0.293 |
| Lab 5 | 0.562 | 0.018 | 0.785 | 0.120 |
| Lab 6 | 0.343 | 0.046 | >0.999† | 0.545 |
| Lab 7 | 0.952 | 0.190 | 0.528 | 0.011 |
| Lab 8 | 0.021 | 0.233 | 0.002* | 0.453 |
| Lab 9 | 0.318 | 0.054 | 0.927 | 0.222 |
| Lab 10 | 0.311 | 0.058 | 0.908 | 0.207 |
| Lab 11 | 0.003* | 0.311 | 0.724 | 0.090 |

*Notes. We performed a left-tailed t-test on mean completion times for each lab;* $H_0: \mu_{Vid} = \mu_{Lec}$ *vs.* $H_0: \mu_{Vid} < \mu_{Lec}$. *Used Bonferroni correction to get significance level* $\alpha = .05 \div 11 = .0045$. *Effect size computed using Cohen's d.*
** p < .0045. † p > .9955 (equivalent to p < .0045, right-tailed).*

**Survey Results**

Next, we outline the results from the post-survey administered to students (see Table 2 for questions). The post-survey was administered in 16 sections of Chem 111 (8 video and 8 lecture) to 352 total participants. Recall that responses ranged from Strongly Agree (5) to Strongly Disagree (1). The post-survey results were analyzed to see if there was a significant difference in attitudes between the two groups. To do this a two-sample t-test for each of the nine questions was performed based on the sample mean Likert scores of the two groups. We tested the hypothesis $H_0^{(k)}: \gamma_{Vid}^{(k)} = \gamma_{Lec}^{(k)}$ of no difference in mean Likert scores, versus that there is a difference $H_a^{(k)}: \gamma_{Vid}^{(k)} \neq \gamma_{Lec}^{(k)}$. Here $\gamma_{Vid}^{(k)}$ and $\gamma_{Lec}^{(k)}$ represent the population mean Likert scores for the video and lecture groups, respectively, for question $k = 1, \dots, 9$. Table 6 gives the sample means for each statement along with the p-value and effect size. With a Bonferroni correction, significance was determined at the $\alpha = 0.05 \div 9 = 0.0056$ level. An asterisk signifies a p-value corresponding to a statistically significant difference being shown.

We see that there were no significant differences in the mean Likert scores except for statement 2 ('Expectations for the labs were well communicated prior to the beginning of the experiment.') and statement 5 ('My laboratory instructor was helpful.'). However, the effect sizes of 0.375 and 0.319, respectively, are on the small side. For both of these statements the mean scores for the lecture group were higher. Based on the p-values from the two-tailed test above we can conclude that this would be a significant result, if we had conducted a one-tailed test with alternative of $H_a : \gamma_{Vid} < \gamma_{Lec}$. For statement 2, we conjecture that the increased mean scores may be explained by students' ability to interject questions or ask for clarification in real-time during the lecture-based pre-laboratory instruction, as opposed to having to hold their question until the conclusion of the video instruction. It is particularly interesting that students in the video pre-laboratory sections felt this way in light of their increased performance on the pre-laboratory quizzes in many instances. A second item worth noting is statement 5 ('My laboratory instructor was helpful.'). Once again, students in the lecture sections tended to agree more strongly to this survey item compared with students in the video sections. While it seems rational that this may be a natural by-product of the increased interactions between the instructor and students in the lecture sections, past studies found undergraduate students were highly satisfied with teacher-to-student interactions in hybrid and online courses (Inman, Kerwin, & Mayes, 1999). This finding warrants additional attention in future research, particularly to see if the presence of the teacher within the laboratory setting (as opposed to a distance learning setting where the teacher is physically in a different location) changes students' perceptions of instructor helpfulness when an alternate mode of delivery is used.

Table 6

*Results of Two Sample T-Tests on Mean Likert-Scale Scores*

| Statement | Video Mean | Lecture Mean | p-value | Effect Size |
|---|---|---|---|---|
| S1 | 4.11 | 4.02 | 0.273 | 0.177 |
| S2 | 4.02 | 4.29 | 0.001* | 0.375 |
| S3 | 3.90 | 3.93 | 0.807 | 0.026 |
| S4 | 3.82 | 4.02 | 0.044 | 0.216 |
| S5 | 4.38 | 4.58 | 0.003* | 0.319 |
| S6 | 4.15 | 4.14 | 0.866 | 0.018 |
| S7 | 4.42 | 4.48 | 0.368 | 0.096 |
| S8 | 4.35 | 4.37 | 0.696 | 0.042 |
| S9 | 3.64 | 3.68 | 0.731 | 0.037 |

*Notes. We performed a two-tailed t-test on mean scores for each statement;* $H_0: \gamma_{Vid} = \gamma_{Lec}$ *vs.* $H_0: \gamma_{Vid} \neq \gamma_{Lec}$. *Used Bonferroni correction to get significance level* $\alpha = .05 \div 9 = .0056$. *Effect size computed using Cohen's d.* *$p < .0056$.*

**Discussion**

The analysis of pre-laboratory quiz scores suggests that students benefitted from receiving pre-laboratory instruction in a video versus lecture format in terms of overall pre-laboratory quiz scores. Furthermore, these benefits appeared similar regardless of student demographics such as gender, year in school, and whether or not the students were native English speakers. As a result, our study supports the use of in-class videos as a mechanism for providing pre-laboratory instruction in an introductory college Chemistry course. However, the results also suggest some important pedagogical considerations for successfully implementing these videos.

A consistent trend across semesters and student sub-populations was a lag in the higher quiz scores for students in the pre-laboratory video sections, with students in the pre-laboratory lecture sections actually outperforming their peers in the video sections on the first two or three quizzes (albeit not statistically significant except for the spring semester on quiz 1). In our digital era, we often assume that students are adept at using videos as learning tools. But the results suggest that students may have required some time to adapt to this mode of in-class instruction. We conjecture that students may have initially been distracted while watching the pre-laboratory videos as they are used to multi-tasking (Brown, 2000; Junco, 2012) or struggled to know how to attend to the information presented within those videos. Researchers have suggested pedagogical strategies to enhance the effectiveness of video-based instructions, including having students answer guiding questions as they watch videos (Lawson, Bodie, Houlette, & Haubner, 2006). Implementing an instructional strategy to accompany the video viewing may help students to adjust to this form of pre-laboratory instruction more quickly than was seen in our results.

The need to consider pedagogical practices to support the implementation of videos is further supported by the post-survey responses. Despite the positive gain in quiz scores for students in the video sections, the post-survey responses showed that these students actually reported feeling less informed prior to the laboratories compared to students in the lecture sections, and they also had less positive attitudes about their laboratory instructor. This supports the work of other researchers who have pointed to the importance of classroom interactions and discussions to accompany video-based and digital learning (Bell & Bull, 2010; Hajhashemi, Caltabiano, & Anderson, 2017). Our study adds to the previous literature by suggesting that videos, in isolation, may actually be an effective mode of delivery in terms of preparing students with background information necessary to succeed in a laboratory environment. However, our research suggests that additional pedagogical consideration should be given to (1) assisting students in watching videos in the most effective manner and (2) maintaining positive classroom dynamics that foster strong relationships and rich interactions between instructor and students.

Whereas past research has shown the effectiveness of pre-laboratory videos in reducing the amount of time it takes students to complete a chemistry laboratory (Nadelson et al., 2014; Burewicz & Miranowicz, 2006), our results did not support this finding. We anticipate that the content of the laboratories may be one reason for this finding. For instance, the foci of the laboratories in general chemistry tend to be about learning technique and using that technique to come to a conclusion (empirical formula, molarity of a solution etc.) that is close to the true value. In other courses, such as organic chemistry, there is a lot of preparation for glassware setups (refluxing, separation of compounds in a mixture etc.) that can be done much more quickly with a visual demonstration via video (Chayor et al., 2017 Nadelson et al., 2014). However, this warrants further investigation.

### Limitations

Although motivated by the desire to increase instructional consistency across multiple laboratory sections, this study did not examine the level of consistency present between sections using either mode of delivery. In particular, although all instructors in the traditional lecture sections were informed of the key points for pre-laboratory instruction, the lectures were not scripted nor monitored for consistency. Similarly, it is possible that some of the video section instructors may have supplemented the videos with additional commentary or points of emphasis. These limitations could be addressed in future research by creating scripted lectures and monitoring the video sections to ensure consistency of delivery. In fact, measuring the consistency of instruction using each mode of delivery is a natural next step in this research since this was the motivating factor in designing the pre-laboratory videos as instructional tools. One additional limitation stems from the fact that the quiz scores were not incorporated in students' course grades, making it possible that some students were not motivated to perform to their full potential.

## Conclusion

Our results support the use of videos as an instructional strategy for providing pre-laboratory information in a chemistry course. In particular, videos are a useful tool to ensure that pre-laboratory instruction is consistent across multiple sections and different instructors. However, care must be taken to ensure that students are aware of the instructional importance of videos, and pedagogical techniques for focusing students' attention on the important features of the videos are encouraged. Based on our findings, we suggest future research continues to investigate this issue by examining how particular pedagogical strategies, such as taking notes or answering guiding questions during the video, impact both the learning curve for videos as an in-class instructional tool as well as students' overall attitudes toward their instructor. It may also be interesting to examine whether the content of the laboratories (e.g., a lot of instrumentation set-up versus implementation and drawing conclusions) affects whether video-based instruction improves time for laboratory completion.

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