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Investigating the Effectiveness of Using Application-Based Science Education Videos in a General Chemistry Lecture Course

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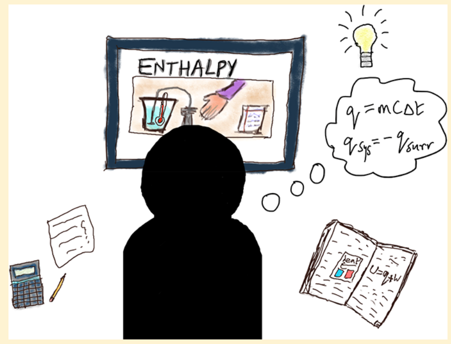
Supporting Information

ABSTRACT: Numerous online resources provide a variety of content for a wide range of STEM topics; however, they tend to function as isolated tidbits that provide content-specific knowledge. Application-based science education videos address the overlooked issue of concept to application by implementing experimental components in their videos and fostering connections with everyday applications. We utilized the *Journal of Visualized Experiments* (JoVE) peer-reviewed science education videos as homework assignments to supplement lectures on the topics of enthalpy, entropy, rate laws, and Le Châtelier's principle in a second-term general chemistry course. Student learning was assessed through the analysis of pre- and post-video conceptual quizzes, and value surveys were also conducted to gather student feedback about the videos. Our investigation shows that using these videos in the course significantly improved student learning and reinforced conceptual understanding for important foundational concepts, and these results hold even for students who did not feel positively toward the videos.



KEYWORDS: *First-Year Undergraduate/General, Multimedia-Based Learning, Internet/Web-Based Learning, Physical Chemistry, Instrumental Methods, Kinetics, Calorimetry/Thermochemistry, Heat Capacity, Equilibrium, Thermodynamics*

■ INTRODUCTION

Incorporating technology in ways that enhance student engagement and learning is crucial for introductory STEM courses due to their large enrollment. To date, instructional videos have been widely used to provide course content and to assess student progress in both lecture and laboratory settings.[1−3] Introducing online homework to supplement face-to-face learning is becoming popular as it supports a well-paced, student-centered, learning environment.[4−6] Numerous online resources (Youtube, homework Web sites, e-learning, etc.) provide a variety of content for a wide range of topics in the STEM disciplines, and their visually appealing format and easy accessibility have made these online resources ubiquitous. Nevertheless, while these resources do a good job of visualizing abstract concepts, they function as isolated tidbits that provide content-specific knowledge. Our students absorb the required information from them, pass their exam, and move on to the next class, quickly "forgetting" what they learned in the process. Past research has illustrated that most issues with chemistry learning arise from students' inability to relate the subject to everyday life.[7−12] We expect our students to intuitively apply the topics learned in theory courses; however, many topics in chemistry can be challenging for students to apply in a different context, and students often learn concepts without a clear understanding of their applications.[11−15] This problem further translates into laboratory courses, where students do not make the association and thereby perform an experiment based off a remote concept without being exposed to its practical application. As a result, students miss out on opportunities to build higher-order cognitive skills such as critical analysis and scientific reasoning and fail to form connections with previous knowledge, both of which are vital for them to evolve from novices to experts.[16] Therefore, there is a need for online resources that provide content in a way that aids in the full understanding of a concept and its applications as well as in creating connections with future courses.

The *Journal of Visualized Experiments* (JoVE) Science Education videos bridge the gap between conceptual understanding and its relevant application by implementing an "Experiment Component" into its videos. These 8−9 min peer-reviewed videos are structured such that a topic is covered conceptually in the first 3 min, after which the video details and demonstrates a laboratory experiment on the topic. The last few minutes of each video summarize the findings of the experiment through non-trivial data analysis, elucidate their implications, and also explain a few real-world applications based on the topic and/or experiment. The discussion surrounding the data analysis further assists in emphasizing the concept and its practical application by drawing parallels

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between the topic and the experiment. Studies show that instructors doing in-class demos during lecture classes largely improve the understanding and application of chemistry concepts.[17] While there are time constraints and instructor/resource limitations that may not allow demonstrations to be employed for all topics, the JoVE Science Education videos present an alternate route that provides students with a virtual way to convey the same principles.

■ METHODS

Participants and Context

Participants were enrolled in a second-term general chemistry lecture course targeting life science/nonchemistry majors. This course can be taken by students only after they complete a first-term general chemistry course taught by various instructors. This course was taught in a traditional lecture format focused on conceptual understanding of the topics and has no laboratory component associated with it. Additionally, this course is considered as a prerequisite or co-requisite for a stand-alone general chemistry laboratory course. Student enrollment comprised 177 students in the winter 2018 quarter and 324 students in the spring 2018 quarter. Both quarters were taught by the same instructor (corresponding author), using near-identical course formats and teaching strategies. The lecture setting was utilized for teaching core concepts as well as solving numerical problems pertaining to the topics. To establish the relevance of these concepts and numerical problems to real-life applications, the JoVE videos were provided as homework assignments.

Implementation

Students were taught the topics pertaining to the video concepts through a traditional lecture format. After learning a particular topic over one or two lectures (50 min duration each), the students were given a 5 min conceptual multiple-choice quiz (paper or scantron) at the end of the lecture period on that topic. The quizzes typically consisted of four or five questions; therefore, students who did not receive a perfect score could receive only ≤80%. Students should be able to answer all the questions on the quiz using information provided in lectures alone (see Box 1). This prevideo quiz was considered as the pretest, and all pretests were administered to students in class to avoid access to other preparatory course resources.

Box 1. Sample Quiz Question on Entropy

If ΔS is calculated to be positive, there is greater disorder in the ___________, which would drive the reaction in the ___________ direction.

(A) reactant(s), forward
(B) product(s), forward
(C) reactant(s), backward
(D) product(s), backward

After this, the students were assigned a JoVE video to watch as homework using the official online course platform. The university's library subscription to JoVE permitted all students to view the video both on-campus and off-campus. Following the video, students were directed to take a postvideo quiz that consisted of the same questions as the pretest and some additional feedback questions regarding the video. The postvideo quiz/posttest could be done only once, and students were provided one point for participation that counted toward their overall homework grade. To eliminate the possibility of students preparing for the quiz using other resources, credit was based on participation and not on their performance on the quiz. In the winter quarter, the posttest was administered online immediately after watching the video, while in the spring quarter, the posttest was administered in the next lecture class using a paper/scantron quiz to allow for a delay of ≤48 h after watching the video. Because the winter quarter posttests were taken online following watching the video, the time between lecture and posttest varied across students, depending on when they had watched the video. However, in the spring quarter, all the posttests were administered in class at the same time for all students. This was done with the intention of mimicking the pretest setting and circumventing the effect of additional course resources such as the textbook or checking for answers on the Internet.

The procedure described above was executed for four videos with not more than one video assigned per week. Students watched videos on four topics: enthalpy, entropy, rate laws, and Le Châtelier's principle. It is important to note that the topics of enthalpy, entropy, and rate laws were covered in the current second-term general chemistry course whereas Le Châtelier's principle was a topic learned in a prior first-term general chemistry course. For that reason, the pretest for the Le Châtelier's principle video was administered in class without covering the topic in lecture. Additionally, it is worth mentioning that the course schedule was carefully planned to ensure that the second-term general chemistry topics were covered to the same extent in lecture(s) during the winter and spring quarters, and the time lapse between the pretests and posttests was kept as similar as possible. There was a small deviation from this class schedule for the rate law topic between the winter and spring quarters, and the effect of this can be seen in our pretest results (see the next section).

■ RESULTS

Student Feedback

Overall, students reported generally positive feedback toward all four JoVE videos that they were assigned to watch. We have made the distinction between videos on topics taught in the current second-term general chemistry course and the prior first-term general chemistry course. Note that the winter quarter students were given three response options (agree, neutral, and disagree) while the spring quarter students were given four response options (strongly agree, agree, disagree, and strongly disagree). Research suggests that when presented with a neutral option, students may use that option as a crutch to not make a decision regarding their attitudes.[18−20] Upon removal of a midpoint option, students must form an opinion one way or the other through careful consideration of their experience and reflecting on their metacognition. To ensure that student opinions were not bimodal due to this change, we provided strongly agree, agree, disagree, and strongly disagree options. As a methodological change exists between the two groups in the winter and spring quarters, we do not combine the feedback from both quarters for data analysis or make direct comparisons between the groups. Strongly agree and agree responses are grouped together in the descriptive statistics reported in Figure 1, and a detailed breakdown of the survey statistics is provided in the Supporting Information.

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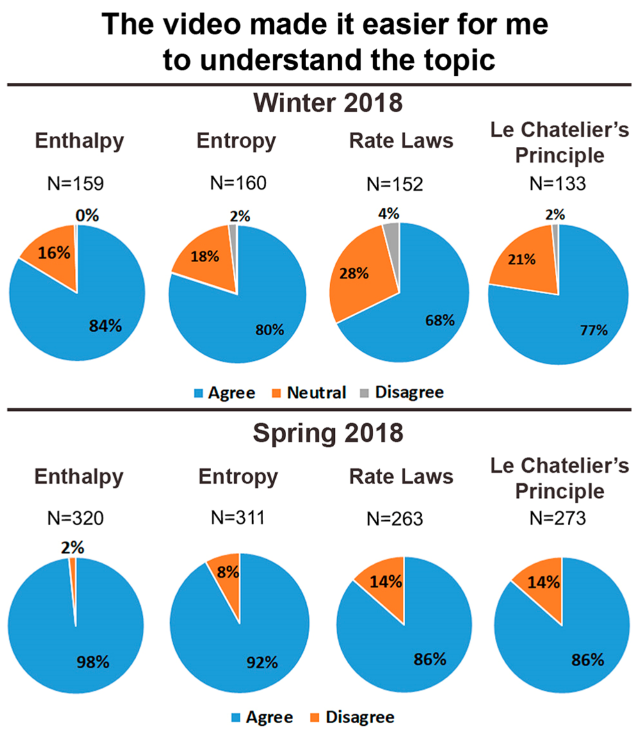

Figure 1. Student responses to the value survey question on whether the video made it easier for them to understand the topic.

For the videos focusing on topics that were taught in the current course, i.e., second-term general chemistry, 84% of the winter quarter students and 98% of the spring quarter students expressed that the enthalpy video made it easier for them to understand the topic of enthalpy. With regard to the Entropy video, 80% of the winter quarter students and 92% of the spring quarter students felt that the video made it easier to understand the topic of entropy. For the video on rate laws, 68% of the winter quarter students and 86% of the spring quarter students agreed that the video made it easier to understand the topic of rate laws. Additional value survey questions and student responses are provided in the Supporting Information.

Interestingly, for the Le Châtelier's principle video that was based on topics that were already taught in a prior first-term general chemistry course, 77% of the winter quarter students and 86% of the spring quarter students felt that the video made it easier to understand Le Châtelier's principle. This was surprising as we had expected that the students may not find this particular video useful, considering that they have an existing foundation in the topic and have been tested on the topic in their previous chemistry course. While looking at the student feedback comments, we noticed that a majority of the students who agreed that the video was effective stated that it reinforced their understanding of the material. One particular comment stood out: "Watching the video helped with this and also understanding Le Chatelier's principle. Previously, I had some incorrect thoughts concerning this principle, but this video cleared it up". Additional student comments regarding all videos are presented in Box 2.

Learning

Paired-sample t tests showed significant learning between the pretests and posttests for all four topics in both the winter and spring quarters, although the amount of learning varied across the topics and quarters (Table 1). As detailed in Methods, the winter quarter posttests were completed immediately after watching the video while spring quarter posttests were completed at a delay of ≤48 h to measure learning rather than immediate performance.[21]

Box 2. Select Student Feedback Comments

- I always enjoy the perspectives shared through both scientific experiments in the laboratory and real-life applications of the concept!
- I really like that they explain each step of the experiment, and then when giving results give an explanation as to why each step was done, and what the outcome of the actions were.
- I liked how the video gave a real example of how to calculate the specific heat capacity of the lead using the values that you could measure. Seeing examples worked out helps me to understand the material better, especially after going over all the topics discussed in lecture.
- I liked that they used experiments to demonstrate the concepts taught. It gave me an idea of how the topics could be used in real life.
- I always enjoy having a visual demonstration of concepts rather than just reading textbook information. I also liked how this video clearly explained how equilibriums were shifting in different situations.

Table 1. Comparative Average Pretest and Posttest Results for the Winter and Spring Quarters

video topic	N	pretest mean (%) (SD)	posttest mean (%) (SD)	t value[a]	effect size[b]
		Winter 2018			
enthalpy	159	71.2 (17.2)	93.5 (10.9)	18.4	1.46
entropy	160	86.4 (19.0)	96.1 (9.1)	6.3	0.50
rate laws	152	38.6 (34.5)	90.4 (20.9)	17.0	1.38
Le Châtelier's principle	133	67.5 (31.2)	93.0 (13.2)	8.8	0.76
		Spring 2018			
enthalpy	320	75.9 (19.5)	94.0 (11.2)	21.8	1.22
entropy	311	88.6 (15.9)	96.9 (8.3)	11.9	0.67
rate laws	263	66.4 (28.0)	95.9 (12.0)	17.1	1.76
Le Châtelier's principle	273	59.6 (18.2)	81.8 (18.2)	14.7	0.89

[a] $p < 0.001$. [b] Cohen's d ("Small, 0.20; Medium, 0.50; Large, 0.80"; as offered by Cohen, 1988).

Enthalpy

The winter quarter students performed significantly better on the enthalpy posttest (M = 93.5%; SD = 10.9%) than on the pretest (M = 71.2%; SD = 17.2%); $t(158) = 18.4$, $p < 0.001$, and $d = 1.46$. The spring quarter students showed a similar pattern of results with posttest scores (M = 94.0%; SD = 11.2%) being significantly higher than pretest scores (M = 75.9%; SD = 19.5%); $t(319) = 21.8$, $p < 0.001$, and $d = 1.22$. When students with perfect pretest scores were excluded from analysis, the effect was even greater. This exclusion was made as nonperfect pretest scores are ≤80% for a five-question test (see Methods). Winter quarter students without perfect pretest scores averaged a score of 93.4% (SD = 11%) on the posttest, improving their score from 69.9% (SD = 16.4%) on the

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pretest; $t(151) = 20.4$, $p < 0.001$, and $d = 1.66$. Spring quarter students without perfect pretest scores averaged a score of 91.9% (SD = 12.3%) on the posttest, improving their score from 67.3% (SD = 15.4%) on the pretest; $t(235) = 31.6$, $p < 0.001$, and $d = 2.06$. For both quarters, the trends observed for the enthalpy pretest and posttest scores were similar. These results are graphically represented in Figure 2.

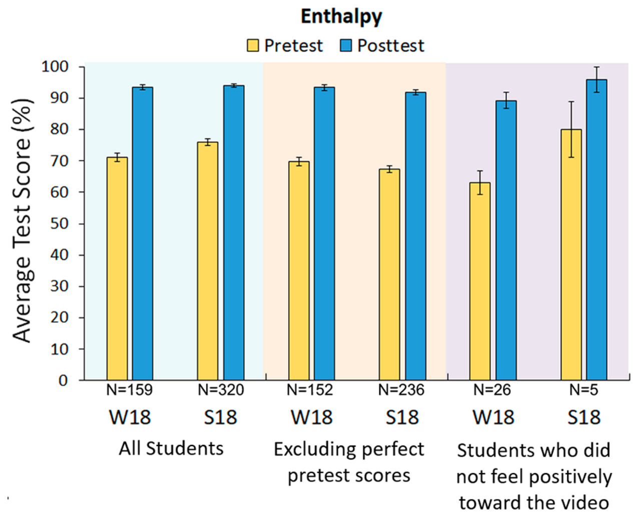

Figure 2. Comparison of pretest and posttest quiz scores in winter 2018 (W18) and spring 2018 (S18) quarters for the JoVE Science Education video on enthalpy. The topics in this video were learned during the current general chemistry course.

Additionally, we wanted to see if the feedback responses of students toward the video affected their learning, particularly for students who did not express positive remarks about the video. The winter quarter students who disagreed or felt neutral toward the video helping make enthalpy easier to understand showed the same pattern of improved performance, scoring an average of 89.2% (SD = 12.9%) on the posttest, improved from an average score of 63.1% (SD = 19.3%) on the pretest; $t(25) = 9.1$, $p < 0.001$, and $d = 1.78$. The spring quarter students who disagreed or strongly disagreed that the video helped make enthalpy easier to learn did show an improvement on the posttest ($M = 96.0\%$; SD = 8.9%) relative to the pretest ($M = 80.0\%$; SD = 11.89%), but the improvement was not statistically significant; $t(4) = 2.1$, $p = 0.09$, and $d = 0.96$. However, the sample size was small in this case, and thus the test underpowered. Numerically, the trend of improved posttest performance continued (Figure 2).

Entropy

For the topic of entropy, the winter quarter students did show a significant improvement on the posttest ($M = 96.1\%$; SD = 9.1%) versus the pretest ($M = 86.4\%$; SD = 19%); $t(159) = 6.3$, $p < 0.001$, and $d = 0.5$. The results of the spring quarter students also displayed a similar trend with significantly higher posttest scores ($M = 96.9\%$; SD = 8.3%) compared to pretest scores ($M = 88.6\%$; SD = 15.9%); $t(310) = 11.9$, $p < 0.001$, and $d = 0.67$. It is important to note that the pretest scores for the entropy topic are high to begin with; however, the observed improvement is still noteworthy. A larger effect could be seen especially when students with perfect pretest scores were excluded from the analysis. Winter quarter students without perfect pretest scores had an average score of 94.2% (SD = 11.4%) on the posttest, improving their score from 69.7% (SD = 17.1%) on the pretest; $t(71) = 10.4$, $p < 0.001$, and $d = 1.23$. Spring quarter students without perfect pretest scores scored an average of 92.2% (SD = 11.6%) on the posttest, improving their score from 71.5% (SD = 12%) on the pretest; $t(124) = 20.9$, $p < 0.001$, and $d = 1.87$. In the case of this topic, as well, the trends observed in the test scores are consistent for both quarters and are depicted in Figure 3.

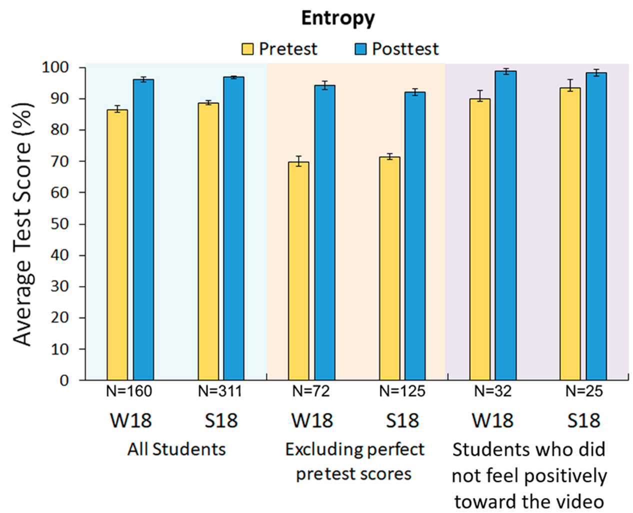

Figure 3. Comparison of pretest and posttest quiz scores in winter 2018 (W18) and spring 2018 (S18) quarters for the JoVE Science Education video on entropy. The topics in this video were learned during the current general chemistry course.

With regard to students who did not feel positively about the video, the winter quarter students who disagreed or felt neutral toward the video helping make entropy easier to understand showed an improved performance, scoring an average of 98.8% (SD = 4.9%) on the posttest from an average score pretest score of 90.0% (SD = 14.4%); $t(31) = 3.3$, $p = 0.003$, and $d = 0.58$. Correspondingly, we observed the same for the spring quarter (Figure 3) where students who disagreed or strongly disagreed that the video helped make entropy easier to learn did significantly better on the posttest ($M = 98.4\%$; SD = 5.5%) than on the pretest ($M = 93.6\%$; SD = 12.5%); $t(24) = 2.3$, $p = 0.03$, and $d = 0.46$.

Rate Laws

Winter quarter students exhibited a significantly better performance on the rate law posttest ($M = 90.4\%$; SD = 20.9%) than on the pretest ($M = 38.6\%$; SD = 34.5%); $t(151) = 17$, $p < 0.001$, and $d = 1.38$. The spring quarter students also revealed significantly higher posttest scores ($M = 95.9\%$; SD = 12%) compared to their pretest scores ($M = 66.4\%$; SD = 28%); $t(262) = 17.1$, $p < 0.001$, and $d = 1.76$. It is worth mentioning that the winter quarter students performed poorer in the pretest than the spring quarter students; however, after watching the video, they seem to be brought up to the same level and show posttest scores comparable to those of the spring quarter students. This observed effect is larger when perfect pretest scores are omitted. Winter quarter students without perfect pretest scores averaged 89.5% (SD = 22%) on the posttest, improving their score from 28.2% (SD = 25.4%) on the pretest; $t(129) = 22.1$, $p < 0.001$, and $d = 1.94$. Spring quarter students without perfect pretest scores had an average score of 94.6% (SD = 13.6%) on the posttest, improving their

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score from 53.8% (SD = 22.3%) on the pretest; $t(190) = 23.2$, $p < 0.001$, and $d = 1.68$. These results are graphically represented in Figure 4.

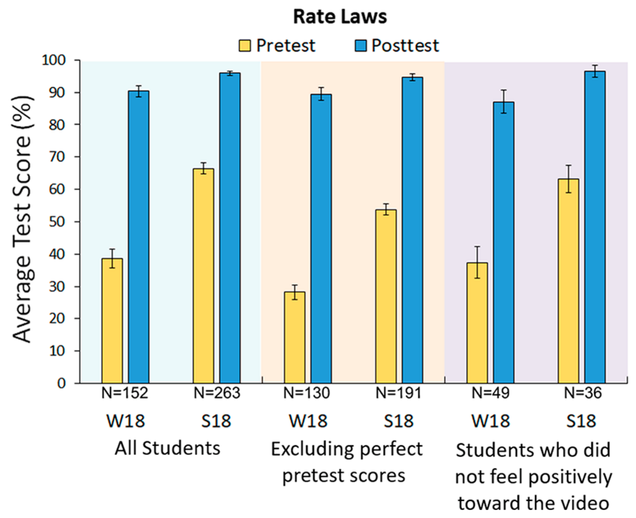

Figure 4. Comparison of pretest and posttest quiz scores in winter 2018 (W18) and spring 2018 (S18) quarters for the JoVE Science Education video on rate laws. The topics in this video were learned during the current general chemistry course.

Additionally, winter quarter students who disagreed or felt neutral toward the video helping make rate laws easier to understand showed an improved posttest average of 87.1% (SD = 25.3%) on the posttest, compared to 37.4% (SD = 34.4%) on the pretest; $t(48) = 8.6$, $p < 0.001$, and $d = 1.23$. Spring quarter students who disagreed or strongly disagreed that video helped make rate laws easier to learn also showed a significant improvement on the posttest score ($M = 96.5\%$; SD = 10.6%) versus the pretest ($M = 63.2\%$; SD = 25.7%); $t(35) = 7.7$, $p < 0.001$, and $d = 1.28$ (see Figure 4).

Le Châtelier's Principle

The topic of Le Châtelier's principle was covered in a previous first-term general chemistry course, and students have been exposed to the material potentially through homework/midterm/final exam. However, the winter quarter students still showed a significant improvement on the Le Châtelier's principle posttest ($M = 93\%$; SD = 13.2%) compared to the pretest ($M = 67.5\%$; SD = 31.2%); $t(132) = 8.8$, $p < 0.001$, and $d = 0.76$. The spring quarter students also followed this trend, with posttest scores ($M = 81.8\%$; SD = 18.2%) being significantly higher than pretest scores ($M = 59.6\%$; SD = 18.2%); $t(272) = 14.7$, $p < 0.001$, and $d = 0.89$. Excluding students with perfect pretest scores increased this effect, showing an average posttest score of 92.0% (SD = 14%) versus a pretest score of 50.9% (SD = 25.6%) in the winter quarter; $t(87) = 12.8$, $p < 0.001$, and $d = 1.37$. Similarly, the average spring posttest score was 81.6% (SD = 18.2%) while the pretest score was only 58.9% (SD = 18.3%); $t(267) = 15.1$, $p < 0.001$, and $d = 0.92$, after excluding perfect pretest scores. These results are graphically represented in Figure 5.

Looking at winter quarter students who disagreed or felt neutral toward the video helping make Le Châtelier's principle easier to understand (Figure 5), we still see the pattern of improved performance with an average score of 91.7% (SD = 15.2%) on the posttest, improved from an average score of

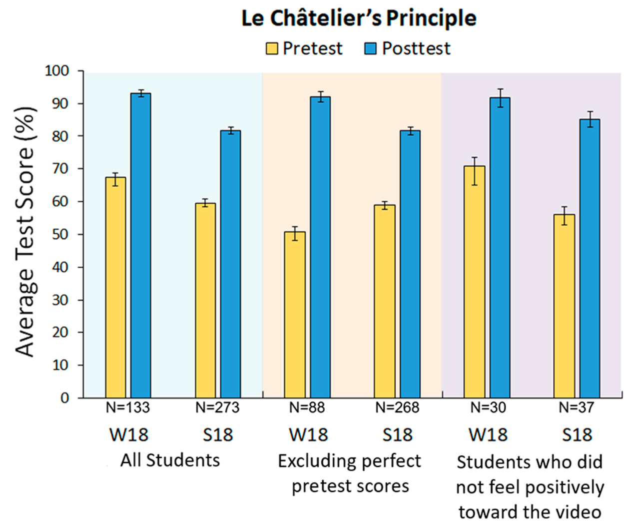

Figure 5. Comparison of pretest and posttest quiz scores in winter 2018 (W18) and spring 2018 (S18) for the JoVE Science Education videos on Le Châtelier's principle. The topic in this video was learned in a previous general chemistry course.

70.8% (SD = 31.5%) on the pretest; $t(29) = 3.3$, $p = 0.002$, and $d = 0.61$. Spring quarter students who disagreed or strongly disagreed that the video helped make Le Châtelier's principle easier to learn also showed significant improvement on the posttest ($M = 85\%$; SD = 15%) relative to the pretest ($M = 56.1\%$; SD = 19.9%); $t(36) = 6.8$, $p < 0.001$, and $d = 1.12$.

■ DISCUSSION AND IMPLICATIONS

Across all topics, students generally expressed that the videos were a useful resource in helping them understand core concepts for the course, and their postvideo quiz performance improved. Even students who disagreed or felt neutral that the videos made it easier to understand the topics showed meaningful gains in posttest scores, in line with the idea that students are not always metacognitively aware of what is best for their own learning.[22] It is, however, important to note that the relatively few students who rated the video as not helpful might have been comparing the video to other resources available or may have felt relatively comfortable with the topic before watching, thus not feeling the video added much to their learning experience (even though it generally appears to have done so). Negative or neutral attitudes toward the video thus do not necessarily reflect the possibility that the videos themselves were poor or ineffective. Future studies should more directly probe why students felt that the video did or did not help. When students who had perfect pretest scores (likely already comfortable with the topics) were excluded, the learning gains were much larger, suggesting that the videos had a greater impact on students who had not yet mastered the topics.

Interestingly, the videos improved student learning for both high-scoring and low-scoring topics. For example, the student performance in the pretest on the topic of entropy was high to begin with; however, the posttest performance still showed a significant improvement. The exclusion of perfect pretest scores was especially useful for looking at a high-scoring topic such as entropy (average pretest score of 86.4%) to see if the video still had an impact on student learning. While most of the students can be considered as already familiar with the material on entropy, their posttest scores still increase after the

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video. The average pretest quiz score for rate laws during the winter quarter was very low, but the posttest performance was much improved, even reaching the same level as those of the spring quarter students who had started out with higher pretest scores. A plausible explanation for the disparity in the rate law pretest scores between the winter and spring quarters is that the students in the spring quarter had an additional weekend before the pretest according to the class schedule, possibly allowing students to go over the textbook reading/notes over that time. The learning results for the entropy and enthalpy topics look very similar across both quarters with students displaying similar pre- and posttest scores.

The Le Châtelier's principle video was initially introduced as a means of ensuring that a foundational concept that should have been taught in a prerequisite course was well-understood. Surprisingly, there was a large difference in the pretest and posttest scores for this topic between the winter and spring quarter students; the spring quarter students performed worse than their winter counterparts in both respects. This was especially evident when looking at the number of students who scored full points on the pretest and posttest (see the Supporting Information), which is surprisingly low for a previously taught topic. Further investigation revealed that the instructor of the previous course in the sequence had not fully covered the topic during lecture. Nevertheless, the spring quarter students still showed large learning gains for the topic, which suggest that the JoVE videos might be a relatively easy way to get students who have a variety of backgrounds and different levels of preparation for a chemistry course on the same page quickly through the use of an outside-of-class assignment. At the same time, the remaining results suggest that the videos are also an effective way to reinforce topics covered in class.

In summary, the JoVE Science Education videos are an effective tool to supplement face-to-face learning. The experimental component in these videos is unique and fosters connections between conceptual learning and application. For topics that were taught in prior courses as well as new topics covered in the current course, the students demonstrated a significant improvement in learning after watching the videos. In an interesting observation, these results hold even for students who state that they did not find the video useful. Furthermore, no appreciable difference was observed between the posttest data for no delay and a 48 h delay between watching the assigned JoVE video and taking the posttest, further illustrating that these videos reinforce conceptual learning. The videos improve performance and necessary foundational or sequential learning without using in-class time and are useful to all students with varying preparation levels.

While the videos cannot function as stand-alone lectures in this classroom setup, they may be useful for that purpose in hybrid flipped classrooms. Future studies comparing posttest results from students watching JoVE videos versus conceptual videos without an experimental component will further strengthen the work presented here. It can also be of value to instructors to compare the learning gains on topics for students who are in the upper half versus lower half, with respect to course performance, to further investigate if these videos produce different learning gains for the two cohorts. Another interesting avenue would be to track these students into the subsequent laboratory course with the intention of evaluating their laboratory performance against students who did not watch the JoVE videos. Ultimately, these videos can be utilized hand in hand to improve learning in the lecture as well as in the laboratory.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.8b00777.

> Student responses to additional value survey questions, addition pretest/posttest data, and sample quiz questions (PDF)

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Notes

The authors declare no competing financial interest.

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