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Embedded questions and targeted feedback transform passive educational videos into effective active learning tools

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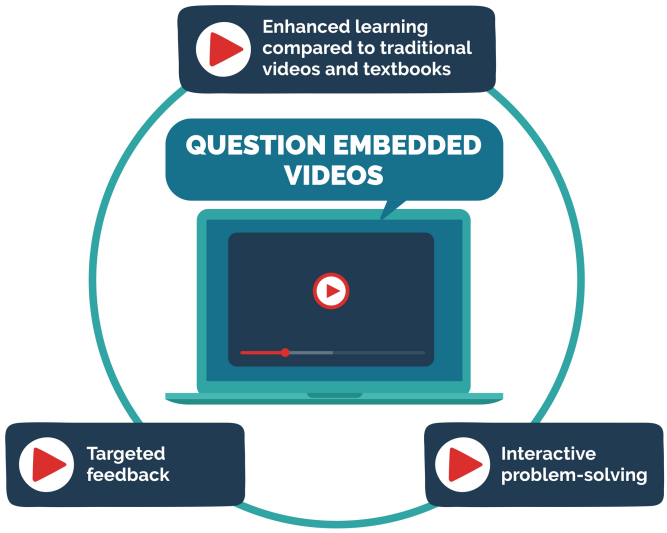
ABSTRACT

Question-embedded videos (QEVs) are learning tools that require students to solve problems and receive immediate targeted feedback while progressing through the video. As an effective learning modality, QEVs may be deployed for the pre-class preparation phase of flipped classrooms. As flipped classrooms become more popular in STEM courses, effective out-of-class preparation is essential to maximize student learning. While previous studies have compared student gains from textbooks and QEVs, this study compares two different types of videos: traditional (narrative) videos and question-embedded videos. While traditional assignments such as narrative videos primarily consist of content delivery, question-embedded videos integrate active problem-solving and are an effective tool in increasing student engagement. The communication discusses separate studies comparing student gains from narrative videos and question-embedded videos for problem-solving from two STEM disciplines: organic chemistry and introductory physics. Students learning from question-embedded videos significantly outperformed students learning from narrative videos. These results suggest that assigning passive narrative videos is not sufficient to yield maximum learning gains for students; rather, assigning out-of-class work with QEVs leads to substantially greater learning gains because of enforced active problem-solving paired with immediate feedback.

GRAPHICAL ABSTRACT



KEYWORDS

High School/Introductory Chemistry, First-Year Undergraduate/General, Distance Learning/Self Instruction, Internet/Web-Based Learning, Multimedia-Based Learning, Student-Centered Learning

INTRODUCTION

Question-embedded videos (QEVs) are asynchronous learning tools that require students to solve problems and receive targeted feedback throughout the video.[1-6] By design, embedded problems enforce student engagement and trigger active learning. While QEVs can serve as standalone instructional resources, they are also effective learning modalities for the pre-class preparation phase of flipped classrooms.[2,3,7-9] Prior research suggests that students learn more in the independent and asynchronous preparation phase of a flipped classroom[10], so finding effective out-of-class teaching methods is critical for maximizing learning gains and promoting equitable learning environments. Although textbook readings have traditionally been the primary out-of-class learning resource,

instructors have been transitioning to using traditional narrative videos, such as those posted on YouTube or Khan Academy, instead.

The proposed benefit of video learning over traditional textbooks is based on cognitive load theory, which describes that there is a limit to how much information we can hold in our working memory before encoding into long-term memory at any given time.[11] Overwhelming cognitive load can hinder a student's ability to effectively encode information. Working memory can be limited by three types of loads: intrinsic, germane, and extraneous.[12] Intrinsic cognitive load refers to the complexity of the information. Germane load describes how much of a student's working memory is allocated for integrating new information into existing knowledge structures. Lastly, extraneous load describes instructional and design elements that increase cognitive load and hinder student learning. Videos combine complementary audio and visual modalities to limit cognitive overload and help students learn more efficiently. Furthermore, videos are often more concise than textbooks, leading to a limited extraneous load and improved germane load, making them more effective resources than textbooks. There are two significant challenges related to engagement when using traditional educational videos for supporting student learning. First, while some instructors and platforms may choose to pair these videos with follow-up questions or quizzes[13], the videos themselves are entirely based on content delivery and do not have embedded questions.[14-16] Unfortunately, the result is that many students often skip videos entirely and only answer the associated questions.[17] The second challenge is that, even for the students that choose to watch the traditional videos, these types of videos do not require students to engage actively in the video lessons. As STEM courses are problem-solving disciplines, emphasizing the development of problem-solving skills can lead to better outcomes with student performance.[18,19]

Question-embedded videos (QEVs) are a new type of educational video designed to achieve even greater learning outcomes. In a recent study, QEVs were found to be more effective in maximizing student learning than content-equivalent textbook readings.[4] QEVs are beneficial resources that combine the cognitive load reduction of traditional videos with active learning and targeted feedback. These features give students the opportunity to engage in the material more deeply, identify gaps in their knowledge, and self-correct their mistakes, further strengthening their metacognitive skills. A

well-designed QEV decreases extraneous cognitive load, increases germane cognitive load, and has enough intrinsic cognitive load to lead to learning gains without overwhelming students.

Although the prior study on the efficacy of QEVs established that students working with QEVs significantly outperform students working from a textbook, the question remains whether the same advantages could be achieved using traditional (narrative) videos or if QEVs are necessary to achieve these learning gains. In this study, we investigate the relative utility of traditional educational videos and question-embedded videos.

METHODS

Two separate studies were used to gauge the efficacy of embedding questions into STEM educational videos. First, a follow-up to a prior study on teaching organic chemistry concepts was performed (study A).[3] The second study compares the relative effectiveness of narrative videos and QEVs for students studying circuits and power, examples of introductory physics concepts (study B). Both studies were reviewed and approved by the Institutional Review Board. Students participating in these studies were enrolled in a large private university in northeastern United States.

All the videos were designed following accepted best-practices for multimedia design principles[1], and then produced using Explain Everything. Finally, embedded multiple-choice problems and feedback were added using Edpuzzle.[20] Students in the QEV groups, after answering each question in the QEV, immediately received pre-populated feedback for all answer choices, followed by step-by-step video explanations of the solution. In these groups, students were unable to continue watching the video until they inputted an answer choice to each question. In both the QEV and narrative groups, skipping portions of the videos was prevented with the “prevent skipping” feature on Edpuzzle.[20] This ensures that students are required to watch the videos in order to complete the video assignments. Though some students may find it limiting, Edpuzzle also does not allow students to change video speed by default, so students were restricted from fast-forwarding or slowing down video speed. Students could rewind and re-watch any portion of the video if they chose to do so.

For both studies, QEVs were scripted and produced in such a way that the actual interrogatory portions of the videos along with all question language could be removed without disturbing the flow of the instruction. The narrative videos were then created by removing the short portions of the videos where the questions were being asked, the embedded questions, and the pre-populated feedback for each answer choice. The step-by-step video explanations of the problem solutions were retained, such that students still received the same direct instruction in both sets of videos. Narrative videos were then uploaded to Edpuzzle to maintain the same presentation format as QEVs. The only difference between the narrative videos and QEVs was that students using narrative videos were not required to pause the video, input answers to problems, and read the pre-populated feedback before seeing step-by-step solutions. In this manner, narrative videos modeled traditional educational videos such as those posted on YouTube or Khan Academy.[14-16]

Students participated in the studies remotely on Zoom.[21] Students were proctored and were required to keep their cameras on throughout the study. Before beginning, verbal consent was obtained from all students and the instructions were read aloud. After the consent, students were given up to 45 minutes to prepare using their randomly-assigned learning resource (textbook excerpts, narrative videos, or QEVs), and no difference ($p > 0.05$) was observed in the amount of time students spent preparing. After completing their preparation, an assessment comprised of multiple-choice and short-answer responses was administered. The assessments for both studies were content validated by professors in the respective courses and the results were shown to be reliable ($\alpha_{\text{assessment,A}} = 0.76$, $\alpha_{\text{assessment,B}} = 0.71$). Assessment scores were calculated as the percentage of problems solved correctly, without any partial credit for incorrect answers.

STUDY A: LEWIS STRUCTURES AND BOND-LINE NOTATION (ORGANIC CHEMISTRY)

The original study[3] included three groups of 27 students (i.e., QEV, textbook, and control) recruited during Summer 2020; in this follow-up, another 27 students were recruited (in Summer 2021) to form an additional experimental group: narrative videos. All students participating in the study were rising sophomores, who had taken general chemistry and were registered to take organic chemistry in the fall. All four groups passed the Shapiro-Wilk test for normality ($p > 0.05$), and no statistical difference

in prior academic performance was detected based on their prior general chemistry course grades (study A, $p > 0.05$). An *a priori* power analysis reveals that this sample size was sufficient to detect effect sizes greater than 0.80 at a power level of 0.80.

In the original study[3], the first QEV video (the octet rule, 4 mins) had eight embedded questions, the second QEV video (organic Lewis structures, 7 mins) had seven embedded questions, and the third QEV video (bond-line notation, 6 mins) had five embedded questions. For the narrative versions, removing the embedded questions decreased video lengths by 30 secs, 34 seconds, and 1 min and 49 seconds, respectively. The assessment from the original study was used to measure learning for students in the narrative group.

STUDY B: INTRODUCTION TO CIRCUITS (PHYSICS)

Participants were undergraduate students who had not taken college-level electricity and magnetism physics courses and who had not taken Advanced Placement or International Baccalaureate physics courses in high school. The randomized control trial design was comprised of 70 students, who were randomly placed into two groups: narrative ($n = 35$) and QEV ($n = 35$). Again, the two groups passed the Shapiro-Wilk test for normality ($p > 0.05$), and no statistical difference in prior academic performance were detected based on their cumulative GPA (study B, $p > 0.05$). An *a priori* power analysis reveals that this sample size was sufficient to detect effect sizes greater than 0.75 at a power level of 0.80.

The first QEV video (introduction to circuits, 5 mins) had 5 embedded questions, the second QEV video (series versus parallel circuits, 8 mins) had 9 embedded questions, and the third video (complex circuits and power, 6 mins) had 7 embedded questions. When converting QEVs to narrative videos, the first video had 1 minute and 6 second removed, the second video had 2 minutes and 40 seconds removed, and the third video had 1 minute and 6 second removed. The assessment from the QEV and narrative group had seven questions, with two questions on calculating total resistance, four questions on current through resistors of parallel and series circuits, and one question on power.

STATISTICAL ANALYSIS

Statistical Package for the Social Sciences (SPSS) version 27 was used for all statistical analysis. All tests were performed at the 95% confidence level. Assessment differences for study A were calculated using ANOVA and post-hoc tests with the Bonferroni correction for multiple comparisons. For study B, the assessment differences were calculated using an independent *t*-test. Effect sizes were reported as eta-squared (η^2) and Cohen's *d*. Eta-squared was interpreted as small (0.01), medium (0.06), or large (0.14).[22] Cohen's *d* was interpreted as small (0.2), medium (0.5), or large (0.8).[23]

RESULTS

ORGANIC CHEMISTRY TOPICS (STUDY A)

A significant and very large difference was detected between the assessment scores of the students in all four groups ($p < 0.001$, $\eta^2 = 0.328$) (Figure 1). Students who studied from QEVs scored substantially better on the assessment than students in the textbook group ($p < 0.001$, $d = 1.243$) or the narrative group ($p < 0.001$, $d = 1.049$). There was no significant difference between students studying from the textbook or the narrative videos ($p > 0.05$, $d = 0.140$).

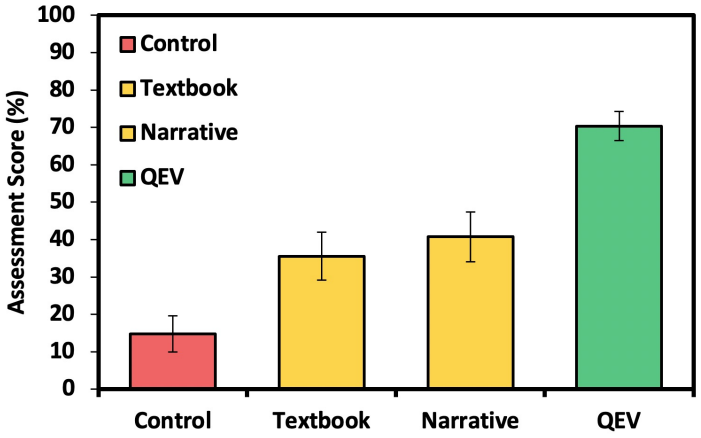


Figure 1. Assessment performance for each experimental group: control (no intervention), textbook, narrative videos, and question-embedded videos (QEVs) with 95% confidence intervals shown as error bars. Students who studied from QEVs scored substantially better on the assessment than students in the textbook group ($p < 0.001$, $d = 1.243$) or the narrative group ($p < 0.001$, $d = 1.049$). (Adapted with permission from reference 3. Copyright 2021 American Chemical Society.)

Looking at the distribution of student performances on the assessment (Figure 2), a clear distinction can be seen between students working with QEVs and students in the other three groups. It is not surprising that more than 80% of students in the control group, who did not get access to any study resources, received unsatisfactory scores; however, it is worth noting that nearly half of students using textbook and narrative videos scored below 40% on the assessment. Conversely, none of the students who prepared using the QEVs received low scores on the assessment (Figure 2).

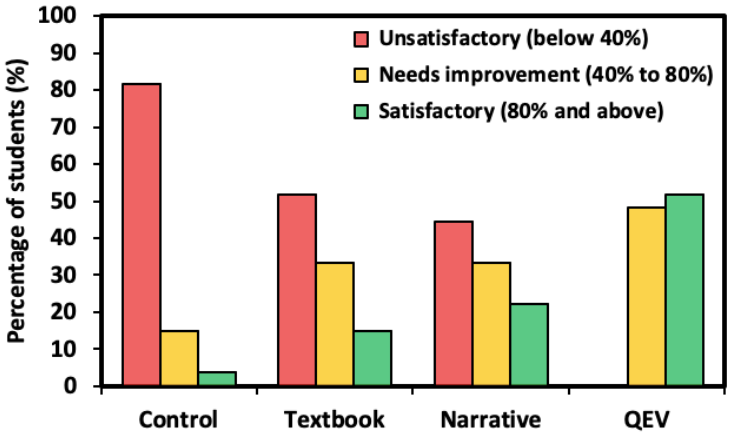


Figure 2. Assessment score distributions for each experimental group (control, textbook, narrative, and QEV): unsatisfactory (below 40%), needs improvement (40%-80%), and satisfactory (80% and above) outcomes. In the control group, 82% of students scored unsatisfactory results (below 40%). In the textbook group, 52% and 45% of students had unsatisfactory outcomes in the textbook and narrative groups, respectively. No students using QEVs had unsatisfactory outcomes; instead, over 50% of students scored above 80%. (Adapted with permission from reference 3. Copyright 2021 American Chemical Society.)

INTRODUCTORY PHYSICS, CIRCUITS (STUDY B)

Relative learning from narrative videos and QEVs was also studied for introductory physics concepts. Similar to the results from the organic chemistry study, a significant and moderate difference in assessment scores was observed for students using QEVs compared to narrative videos (M_{QEV} = 71.8%, $M_{narrative}$ = 60.81%, $p < 0.05$, $d = 0.531$). The narrative group had 21% of students score below

40% on the assessment and 56% of students score between 40 and 60% (Figure 3). Conversely, none of the students in the QEV group scored below 40% and had nearly half of the students scored 80% or above (figure 3). This improvement in score distributions for QEVs compared to narrative videos is very similar to the outcome observed in Study A.

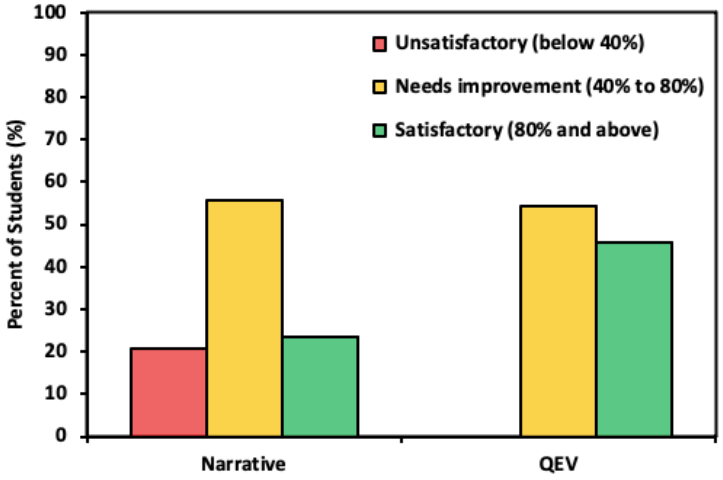


Figure 3. Assessment score distribution for narrative and QEV groups. In the narrative group, 21% of students had unsatisfactory outcomes (below 40%) and 56% of students earned "Needs improvement" (between 40% and 80%). Meanwhile, no students using QEVs scored below 40%, and nearly half of students using QEVs scored 80% or above.

DISCUSSION

The results of the organic chemistry and the physics studies collectively indicate that students preparing with QEVs significantly outperform students that learn from traditional (narrative) videos or content-equivalent textbook sections. Moreover, despite previous evidence[24] that traditional videos have advantages over text-based learning, we observed no statistical difference between students learning from the narrative videos and those learning from textbooks. Therefore, as instructors move towards assigning videos for asynchronous student learning, they should consider that traditional (narrative) video assignments may not maximize student learning or offer any advantage over assigned textbook readings; rather, assigning QEVs will likely lead to significant improvement in student learning out-of-class.

It has previously been suggested that students find textbooks less motivating than videos and thus are less likely to read textbooks than watch videos.[25,26] Plus, students tend to skip over the problem-solving opportunities when working through the text.[27] Nonetheless, despite this student preference for video-based instruction, the students working from narrative videos in the studies reported here did not outperform students learning from content-equivalent textbook readings. Previous findings also note that within a group of students learning from assigned textbook readings, students who attempted to solve problems did not perform better than those who did not attempt problems.[3] Instead, the combination of enforced problem-solving and immediate pre-populated feedback in the QEVs was most likely responsible for the significant learning gains achieved, compared to the narrative videos or textbook readings. For that reason, we recommend flipped-classroom practitioners to consider embedding questions in their assigned videos in order to maximize asynchronous student learning.

The effect size when comparing learning between QEVs and narrative videos was large (d = 1.049) for the organic chemistry study, while the similarly significant comparison for the physics study had only a medium effect size (d = 0.531). It is possible that this difference in relative efficacy may be related to differences in intrinsic cognitive load between the topics.[12] The organic chemistry study covered three topics: the octet rule, organic Lewis-structures, and bond-line notation, whereas the physics study videos covered series circuits, parallel circuits, complex circuits, and power. The increased intrinsic difficulty of the Lewis structure topics, and the additional visuo-spatial skills required for organic chemistry appear to make QEVs even more advantageous. In QEVs, germane load is also improved as the embedded questions and the feedback implicitly helps students identify learning objectives and form additional connections to prior knowledge. Conversely, in narrative videos, there is less instructional guidance and so generative processing, or germane load is relatively lower. Although this drawback is improved in all QEVs, the benefit is most pronounced in topics with high intrinsic cognitive load.

LIMITATIONS

This study has demonstrated that students using QEVs for out-of-class preparation outperform students using content-equivalent traditional resources, such as textbook readings and narrative videos. One inherent limitation of this controlled experiment is that the benefits of using QEVs in full-scale courses is not examined. In a course, some students may choose not to engage with the assigned out-of-class learning resources like they did in the controlled study environment. Additionally, the utility of these videos has only been assessed in the context of short-term learning: using them to prepare for class. In a full course, learning continues after the preparation with in-class instruction, active learning, and studying for assessments. Nonetheless, the conclusion that we draw from this study is that when students *do* choose to engage in their assigned out-of-class preparation, using QEVs is more effective than traditional (narrative) videos or textbook readings for class preparation.

CONCLUSION

This study reveals that traditional narrative videos – ones without embedded questions or targeted feedback – are not sufficient to maximize student learning in preparation for class. Conversely, question-embedded videos (QEVs) best support student out-of-class learning by promoting active learning during the video lessons and helping students to monitor their learning through targeted feedback. Additionally, since the questions are embedded in the videos, and students are not permitted to skip ahead while learning, QEVs hold students more accountable for completing the learning assignments when embedded in course learning management systems.

Given the importance of the learning that takes place outside the classroom, adopting the teaching tools that best support all students is a high priority. Current research suggests that QEVs may offer benefits for students with autism spectrum disorder, ADHD, and other learning disabilities, also leading to more inclusive learning environments.[28-31] Overall, the results continue to demonstrate that well-designed question-embedded videos are more utile than traditional videos or textbook readings, and lead to greater student learning gains through active problem-solving and targeted feedback.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI:

10.1021/acs.jchemed.XXXXXXX.

Supporting Information - Access to Edpuzzle Videos.docx (Word)

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NOTES

The authors declare no competing financial interest.

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