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Impact of Lecture Video Acceleration in a Flipped Introductory Engineering Course*

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As demand for engineers grows, emphasis is increasingly placed on introductory engineering courses to engage, educate, and retain students. Team-Based Learning (TBL) is a pedagogy that shifts instruction from a lecture-based paradigm to a structured learning sequence that includes individual preparation outside of class followed by active, in-class problem-solving exercises completed by student teams. As part of the individual preparation, students may watch recorded videos of lectures, often at an accelerated speed. While the acceleration of videos has the potential to increase students' learning efficiency, the impact on comprehension is unclear. Two studies were conducted to understand students' viewing habits of video lectures, and to determine whether video acceleration and training can increase students' learning efficiency without significant loss in comprehension. A preliminary study surveyed university students from an introductory engineering course on Decision Support Systems and Computer Programming about their lecture video viewing habits, and found that a sizable subset of students watch videos at an accelerated rate. The main study placed students in one of three groups that practiced watching videos at 1X (n = 16), 2X (n = 16), and 3X speed (n = 15), and then tested comprehension at 3X. Results from the preliminary survey revealed that approximately 30% of the students watched the preparatory videos at accelerated speeds in their introductory engineering course. Results from the main study showed that participants were able to accelerate videos up to 2X and with practice, able to maintain the same comprehension levels as participants watching at normal (1X) speed, whose comprehension levels decreased over time. However, 3X acceleration lowered comprehension, regardless of practice at higher speeds.

Keywords: team-based learning; video acceleration; flipped classroom; active learning

1. Introduction

This paper analyzes the use and impact of outside-of-class lecture videos within a team-based learning (TBL) pedagogy through two complimentery studies that investigate:

1. Students' lecture video viewing habits in terms of percent of videos watched and at what video speeds in their introductory engineering course;
2. The trade-off between video acceleration and comprehension, and whether video acceleration and training can increase students' learning efficiency without significant loss in comprehension.

A majority of university students (59%) find at least half of their traditional classes boring, which causes 75% of them to daydream during class [1]. Even the most dedicated students have trouble with traditional lectures, typically losing focus 10 to 18 minutes after a lecture has begun for various amounts of time [2].

While sitting through a boring lecture may be tedious, it also has serious societal repercussions. Boredom has been one of the most cited reasons by students for leaving school, either temporarily or permanently [1]. This is especially important for engineering education because the attrition rate for engineers has hovered around 50% for the last 60 years, which is much higher than other fields of study [3, 4]. Although recent years have shown that engineering attrition rates may be drawing closer to other disciplines, attrition rates are still an area of concern due to the continued demand for engineers [5].

Society cannot afford to lose potential engineers; there is already a global shortage. For example, Africa needs 2.5 million *more* engineers to ensure that basic needs are met, and other developing countries have similar engineering needs [4]. In the United States, there will be a shortage of one million college graduates in the Science, Technology, Engineering, and Mathematics (STEM) fields in the next decade [6]. Thus, the education and retention of undergraduate engineering students has been an ongoing goal of the National Science Board, National Science Foundation, and President's Council for many years [7].

To retain students, researchers have focused on several key factors that affect retention, including classroom/academic climate, low course grades, and low conceptual understanding [4]. Interactive classrooms have been shown to increase the feeling of openness in the classroom climate, which can lead to lower attrition rates [5, 7]. Team-based learning has shown promise in increasing classroom engagement and student performance. TBL can incorporate a flipped (or inverted) classroom, which requires

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students to learn content prior to its application in class [8]. Content transmission, where initial student learning happens, occurs before class time, usually through lecture videos and/or readings. Approximately 40% of the subject's content should be understood by students after this external learning activity [9]. Class time can then focus on more active learning strategies. Class time is used to ensure that pre-class learning was successful and to apply that learning to complex problems solved by teams of five to seven students. A Readiness Assurance Test (RAT) is a formative assessment of their initial out-of-class learning of the material, given at the start of class to students individually. Once completed, teams collaboratively complete the same RAT, iterating until each question has been correctly answered. Following each RAT, the instructor gives a mini-lecture based on the discussion of the questions to address any shortcomings in student understanding.

One of the main goals of TBL is to facilitate teams of students to solve these complex problems more effectively and efficiently, and thus, enable students to learn and do more than if they were working individually. Courses that contain a significant amount of information coupled with the goal of applying course content to solve problems are particularly well suited to the TBL pedagogy [9]. A majority of introductory engineering courses taught at four-year institutions satisfy these two conditions, including the course discussed in this paper. TBL has been shown to enhance learning [10–13], and to increase student retention [14, 15]. TBL helps at-risk students continue and complete coursework, partially because its use allows an instructor to develop stronger relationships with his or her students [16].

In a TBL setting, the initial learning of a subject occurs before class, which requires student accountability. Flipping a class by requiring students to watch videos outside of class has the benefit of increasing the amount of time for active problem solving within class time with the instructor present to scaffold the activity. However, the effectiveness of watching video outside of class may be influenced by the quality of the video, distractions while watching, the inability to ask questions in real-time, and difficulties with comprehension for non-native-language students [17]. Furthermore, students may not watch the videos at all, given the increased accountability this places on them. Since first-year students have varied previous academic experience, the level of student accountability will differ drastically by student. Diverse backgrounds also influence how students adjust to new pedagogies because some students may only have experience with traditional lecture. Students may feel abandoned, or unable to make the transition from the traditional lecture-based, teacher-centric class format [18]. The increased workload that university students have compared to high school [19], combined with the increased probability of engineering students to drop out compared to other fields of study [3, 4], requires more research on how first-year engineering students cope with the demands of team-based learning.

In addition to accountability, another question concerns the use of various mediums and methods through which learning takes place. The first, preliminary study addressed this question by surveying students to understand what mediums and methods they used to prepare for class. Study 1 raised questions about the effectiveness and learning efficiency of lecture videos because students noted they can accelerate videos to increase learning efficiency and decrease boredom. Research shows that faster speaking rates can be up to two times as engaging as normal speaking rates [20]. While video acceleration has its benefits, the concern is that too much acceleration can detrimentally affect comprehension. Thus, the second, main study addressed video acceleration to quantify the trade-offs between comprehension and video acceleration, as well as how practice watching accelerated videos affects this trade-off.

2. Related work

Many areas of study are relevant to the issues described previously. The effects of increasing audio-speed, visual-speed (speed-reading), and video-speed are reviewed to understand how each affects a person's ability to acquire knowledge and are related to a student's ability to comprehend accelerated video lectures.

2.1 The effect of content acceleration on knowledge acquisition and comprehension

Students have higher affective learning when listening to speech at 213 words per minute (wpm) compared to 116 wpm [21]. Higher levels of affect lead to higher engagement [22]. Other studies have shown quantitatively [23] or qualitatively [24] that students' attention and engagement improve with accelerated video because the increased speed forces them to focus.

Research studies have confirmed that 250–300 wpm is the maximum rate at which people can read text or listen to compressed speech and still maintain full comprehension, defined as >90% [25–33]. This rate of 250–300 wpm is twice the speed of the average person's speaking rate [34]. Unaccelerated speech in traditional in-class lectures may leave a portion of a student's cognitive capacity available

[34], which some students use to actively question and comprehend the lecture with internal dialogue, but which others may use to daydream, think about unrelated topics, or interact with electronic devices. A survey in 2015 found that students spent 20.9% of class time using a digital device for non-class activities [35]. Thinking about other topics causes students to disengage from the lecture [1]. Thus, accelerated lecture videos may help keep students engaged.

There are many types of lecture videos: moving images (e.g., [36]), still images (e.g., [37]), writing on blank background (e.g., [38]), and multiple screens of still and moving images (e.g., [39]), among others. Lecture videos may differ in type, but all comprise both visual and audio sources of information. The speed with which this information is delivered is an important factor for student engagement and comprehension [20, 23].

2.2 Trainability of comprehension for accelerated audio

One study showed that participants were able to understand audio at 380 wpm with the same level of comprehension as if they were listening to audio at normal speed (190 wpm) after seven minutes of practice listening to audio at 380 wpm [40]. Another study showed that it took 8–10 hours of practice to understand audio at 325 wpm at the same level as normal speed (125–175 wpm) [32]. Blind adults who have daily practice with an audio synthesizer which reads text at an accelerated pace have been shown to comprehend audio at 512 wpm [41] or 792 wpm [42]; this is significantly higher than the comprehension rate of under 400 wpm for most sighted adults.

Simultaneous reading and listening has shown that people can understand up to 304 wpm, which is higher than reading or listening at normal speed (125–175 wpm) [43]. Other study participants have understood 350 wpm at 80% comprehension [44].

2.3 Comprehension of accelerated video

A limited number of studies address comprehension with video acceleration. A study with video of moving images and audio found that comprehension declined significantly in the 225–300 wpm range, and participants rarely accelerated past the 250 wpm range [36]. Another study used audio and still images with very little text, and similarly demonstrated that "50% [video] compression (2X; 328 wpm) is too fast for learning to take place" because cognitive load increased and post-test comprehension scores decreased substantially [37]. However, these negative effects were not seen at 25% compression (219 wpm) [37].

2.4 Preference for accelerated video

Media, especially commercials, have long used accelerated video due to its ability to save time and its favorable effect on viewers' preferences [23]. Viewers perceive people in accelerated media as having higher confidence and credibility compared to those in normal media [23]. Thus, acceleration elicits favorable effects for persuasion. Media typically compresses videos 5–10%, but sometimes goes as high as 20%, which still can go unnoticed by viewers [23].

3. Preliminary study: Video-speed preferences

A preliminary study analyzed how many students were using the lecture videos and the speed at which they watched them. A weekly survey was given to students through the first ten non-exam weeks of an introductory engineering course on Decision Support Systems and Computer Programming. The purpose was to understand if the students watched the lecture videos and if they did watch them, whether students accelerated, decelerated, or maintained a "normal" video-speed.

3.1 Participants

This study was conducted with a class of 49 students (39 male, 10 female). Because the weekly survey was optional, the number of students who took it varied weekly from 30 to 47. Students were all in the industrial engineering major, and over 90% were first-year students. They had a median age of 19 years old (range: 18–31).

3.2 Dependent variables

A survey was given after each RAT. It consisted of three questions, with allowable responses shown in brackets:

1. *Did you mainly read the textbook, watch the videos, do both, or do neither to study for this RAT?* [Textbook, Videos, Both, Neither]
2. *What percentage of this week's videos did you watch?* [0%, 1–33%, 34–67%, 68–100%, >100% (watched multiple times)]
3. *If you watched the videos, on average, at what speed did you watch the videos?* [0.5 × speed, normal speed, 1.5 × speed, 2.0 × speed]

3.3 Results

On average each week, 73% of the students watched the videos only (M = 56%, SE = 3.4%) or watched the videos and read the textbook (M = 17%, SE = 1.7%). Simliarly, 22% (SE = 2.7%) of the students only read the textbook (see Fig. 1). On average, 5% (SE = 2.2%) used neither.

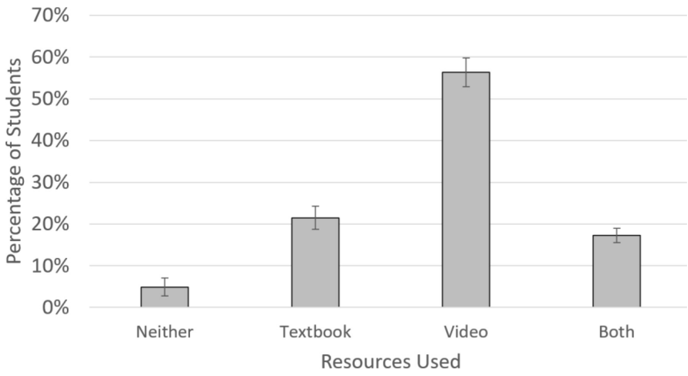

Fig. 1. Student response average and standard error for resource usage (n = 365; 30–47 students for 10 weeks).

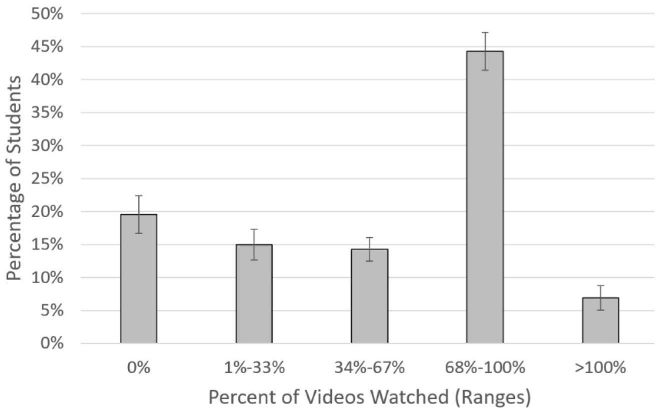

Fig. 2. Student response for percentage of videos watched—semester average and standard error (n = 365; 30–47 students for 10 weeks).

The majority (M = 51%, SE = 4.7%) of the class watched at least two-thirds of the videos throughout the semester (see Fig. 2). However, an average of 20% per week (SE = 2.9%) of the class watched none of the videos. The remaining 29% (SE = 4.1%) watched some, but less than two-thirds, of the videos.

Figure 3 shows the semester average for the speeds at which students watched the lecture videos. The majority (M = 70%, SE = 2.4%) of students watched videos at the 1X (or "normal") speed, but 23% (SE = 2.0%) watched at 1.5X and 7% (SE = 1.9%) watched at 2X.

Responses to the three survey questions changed over the semester. The percentage of students who watched video varied from 60% to 89% depending on the week. For the first six weeks in the survey, 23–28% accelerated videos. However, towards the end of the semester, more students accelerated videos, culminating with 47% accelerating the videos in week 10.

3.4 Discussion

In the TBL classes, videos were used by 73% of students, which was almost twice as many as those who used only the textbook. Approximately 30%

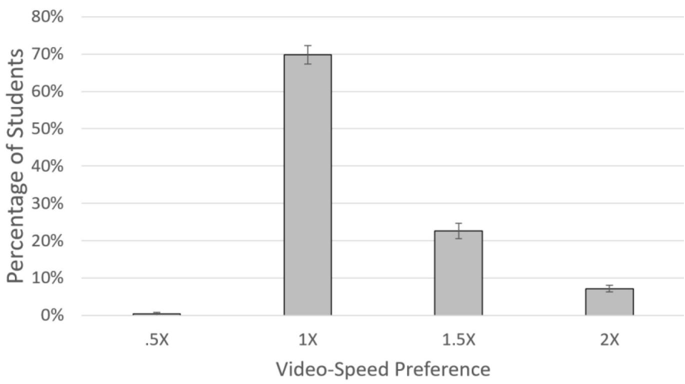

Fig. 3. Student response about video-speed preference - semester average and standard error (n=365; 30-47 students for 10 weeks).

of the first-year students preferred accelerating videos throughout the semester. By the end of the semester, almost half of the students were accelerating the videos. Of those students, 75% accelerated to 1.5X and 25% accelerated to 2X normal video speed. Several factors may have affected their decisions to accelerate the video. First, students could have been concerned that accelerating the video would cause them to miss content. Second, sighted adults have a preference for 175 wpm, which is approximately 1.25X to 1.5X the normal speaking rate [45]. Third, previous research has shown that listening to audio alone at 1.5X normal speed does not increase cognitive load, but listening to audio at 2X normal speed does [37]. Thus, students may have hesitated to accelerate the video past 250 wpm, which is approximately 1.75X the normal speaking rate [36]. This preliminary study showed that students were watching and accelerating the lecture videos within these preferences. However, it was unclear how video acceleration affected their comprehension. This formed the motivation for the main study.

4. Main study: Methods

This study investigated the trade-off between video acceleration, video acceleration training, and student comprehension of video lectures. The study was conducted to determine whether the video acceleration habits discovered in the preliminary study were productive.

4.1 Hypotheses

H1. Without practice, video acceleration will result in lower comprehension and higher cognitive workload.

H2. With a minimal amount of practice watching accelerated videos, comprehension of accelerated videos will increase from its initial levels.

4.2 Participants

Participants included 47 (33 male, 14 female) students with a mean age of 20 (range: 18–31 years), from two different sections of the same introductory undergraduate industrial engineering course. Participants received extra credit for completing the experiment.

4.3 Tasks

Participants watched six different videos at preselected video speeds. Participants could change volume but not video speed. Participants were not allowed to take notes during the tasks. The six videos were standardized to be as similar as possible in terms of content, speaker, and presentation of information. They all came from the Khan Academy® website, had the same speaker, and used the same method of information presentation (writing/drawing on the screen). Khan Academy was selected because it has proven to be a very effective educational resource. With 10 million students worldwide and 3,400 lecture videos, Khan Academy has become an extensive and accessible resource for educators to use in flipped classrooms [38, 46]. Even though the same speaker taught each video, each video initially had different normal speaking rate (video speeds), varying from 154 to 188 wpm (M = 169 wpm, SD = 11.4 wpm). Thus, videos were adjusted to a 1X video-speed standard of 179 wpm. The selected videos were aimed at high school or introductory university students, so the complexity of the information presented was at or below the skill level of the university students participating in the study. Pilot experiments were done with eighteen students to ensure that the levels of comprehension were as equivalent as possible. The videos had a mean time of 9 minutes and a range of 7:39 to 9:49 m:s.

4.4 Independent variables

There were two independent variables in this study: *practice-speed group* (1X, 2X, 3X) and *trial number* (Baseline: T1, Practice: T2–T5, Test: T6). In the practice-speed group***s***, participants conducted the practice trials (T2–T5) at one of three speeds: 179 wpm (1X), 358 wpm (2X), and 573 wpm (3X). For the trial number independent variable, participants each completed six trials: baseline (T1), practice trials (T2-T5), and test (T6). Trial 1 was the baseline and was conducted at 179 wpm. Practice trials T2 through T5 were conducted at the practice speed of the group to which the participant was assigned (1X, 2X, 3X). Finally, test trial (T6) was conducted at 3X. Four practice trials (T2–T5) were used so that at the highest video acceleration (3X) would still total at least seven minutes of practice during the practice trials, since seven minutes resulted in speech comprehension improvement in the Voor & Miller study [40].

4.5 Dependent variables

The dependent variables are described in Table 1.

Comprehension Level was measured via a seven-question, multiple choice quiz taken by a participant after each video that asked them to recall facts from the videos. All quiz questions were at the knowledge level of Bloom's Taxonomy [47]. Participants selected from five possible answers. The questions were created using multiple-choice question writing guidelines [48–50].

Comprehension after Video-Speed Acceleration was measured by comparing the comprehension level after an increase in video speed from one

Table 1. Metrics for the Dependent Variables

Variables	Metric	Units	Frequency	Data Type
Comprehension Level	Comprehension Quiz Score	Points	After each trial	Objective
Effect of Video-Speed Acceleration	With No practice: Difference in Quiz Scores (T2–T1) With practice: Difference in Quiz Scores (T6–T5)	Points Points	Once Once	Objective Objective
Practice Effect	Difference in Quiz Scores (T5–T2)	Points	Once	Objective
Learning Efficiency	Comprehension Quiz Score per Minutes of Video	Points/Min	After each trial	Objective
Cognitive Workload	NASA TLX Scale	Scale 0–60	After Trials 1, 5, 6	Subjective

Table 2. Video Speed Experimental Design

	Baseline	Practice Trials (T2-T5)				Test
Practice-Speed Group	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**
1X Practice-Speed Group	1X	1X	1X	1X	1X	3X
2X Practice-Speed Group	1X	2X	2X	2X	2X	3X
3X Practice-Speed Group	1X	3X	3X	3X	3X	3X

video to the next. The first change in video speed occurred from Trial 1 (1X) to Trial 2 (2X or 3X) for the participants in both the 2X and 3X practice-speed groups. This measured the comprehension effect of video speed change after no training. The second change in video speed occurred from Trial 5 (1X or 2X) to Trial 6 (3X) for both the 1X and 2X practice-speed groups. This measured the comprehension effect of a video speed change after training.

Practice Effect was measured by comparing the comprehension levels at the beginning (T2) and end (T5) of the practice trials. It was used to determine whether practice watching at one of the three video speeds increased subsequent video comprehension.

Learning Efficiency was measured by the comprehension quiz score for a given video and the time taken to watch it. Since the videos were different durations and were counterbalanced across trials, an average time of 9 minutes was used for videos at the 1X video speed. Thus, the comprehension score was divided by 9 for the 1X video speed, 4.5 for the 2X video-speed, and 3 for the 3X video speed. These were the average video lengths for the three video speeds conditions. Average time per video provided a consistent baseline, since the comprehension quiz always consisted of the same number of questions. This metric demonstrated how efficiently participants could comprehend information from different video speeds.

Cognitive Workload was measured via the NASA Task Load Index (TLX). NASA TLX is a subjective survey used to measure aspects of workload, including mental demand [51].

4.6 Experimental design

This experiment was a six (trial: T1–T6) by three (practice-speed group: 1X, 2X, 3X) mixed-subject design. To test the effects of different video speed, participants were randomly divided into three groups: 1X (179 wpm) practice-speed, 2X (358 wpm), and 3X (573 wpm). The 1X and 2X practice-speed groups each had 16 participants and the 3X practice-speed group had 15 participants. The three groups completed six trials. Table 2 shows how the three video speeds were distributed across the experiment based on the independent variables: *Practice-Speed Group* and *Trial Number*. Videos and associated quizzes were counterbalanced using a 6×6 Latin Square.

4.7 Testing environment

The experiment was conducted in a reserved university classroom with 25 Dell Optiplex 980 desktop PCs with dual 24″ widescreen monitors. The videos, quizzes, and surveys were accessed through Blackboard on the Google Chrome Browser in full-screen mode. The participants used headphones so as not to disturb other students participating in the experiment.

4.8 Procedure

The experiment had from one to nine participants per session with each session lasting under 2 hours. Each session began with the informed consent process. Participants were briefed and randomly assigned to one of the three practice-speeds groups. Participants practiced with a warm-up video and quiz. After filling out the pre-experiment survey, participants began the video trials. After each video, participants took the comprehension quiz, with no time limit for completion. Cognitive load was measured after Trial 1, Trial 5, and Trial 6. After Trial 3 and Trial 5, participants took a five-

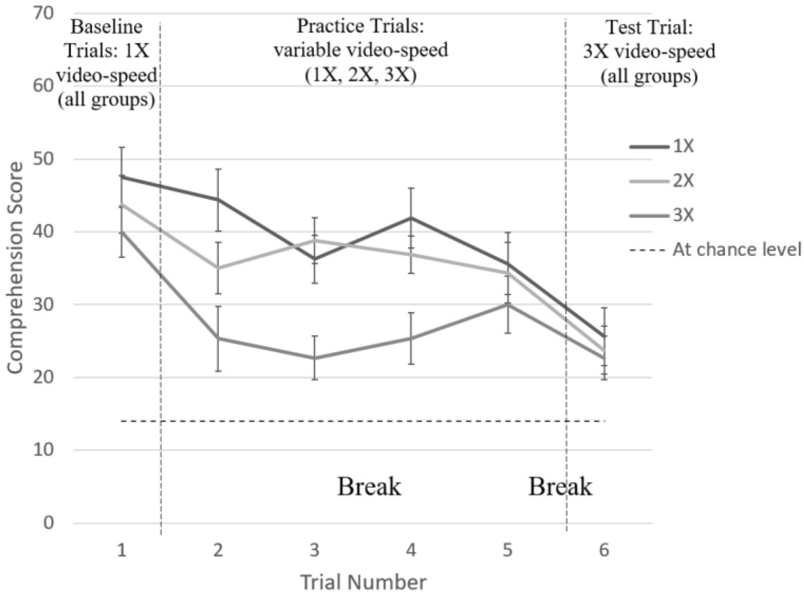

Fig. 4. Comprehension score across six trials and the three practice groups: 1X (n = 16), 2X (n = 16), and 3X speed (n = 15). *Break*: Five-minute break was given between Trials 3 and 4, and Trials 5 and 6. Error bars represent standard error.

minute break to minimize fatigue. Participants were debriefed at the end of the experiment.

4.9 Data analysis

ANOVA analyses were performed for comprehension score, workload, and learning efficiency. An alpha level less than 0.001 was considered highly significant, an alpha level less than 0.05 was considered significant and an alpha level less than 0.10 was considered marginally significant [52]. Cohen's d measured effect size of the mean difference between two groups in standard deviation units, and was reported as small ($0.20 < d < 0.50$), medium ($0.50 < d < 0.80$), and large ($d > 0.80$). The following variables were also analyzed but did not significantly affect any of the metrics, and thus are not included in the results section: gender, whether the participant was a native English speaker or not, class standing, grade point average, and prior experience with accelerated video.

5. Main study results

5.1 Comprehension level

Practice-speed group was highly significant, $F(2,279) = 11.7$, $p < 0.001$. Trial number was also highly significant, $F(5,276) = 7.95$, $p < 0.001$. However, their interaction was not significant (see Fig. 4).

In the baseline trial (Trial 1), there was no significant difference in comprehension between the three practice-speed groups. In the practice trials (Trials 2–5), the practice-speed group had a highly significant effect on the average comprehension level, $F(2,185) = 14.6$, $p < 0.001$. The 3X practice-speed group had highly significantly lower comprehension scores than both the 1X practice-speed group ($F(1,185) = 27.0$, $p < 0.001$, d = 0.90) and the 2X practice-speed group ($F(1,185) = 15.6$, $p = 0.001$, d = 0.75) during the practice trials. However, comprehension scores for the 1X and 2X practice-speed groups were not significantly different across the practice trials.

In Trial 2, comprehension levels for all three practice-speed groups were marginally significantly different from each other (see Table 3).

For the rest of the practice trials (Trials 3 through 5), the 2X practice-speed group's comprehension of videos sufficiently improved over time so that there was no significant difference between their comprehension and that of the 1X practice-speed group's comprehension after the first practice trial. The 2X and 3X practice-speed groups' comprehension scores were significantly different in Trial 3 ($F(1,264) = 9.26$, $p = 0.003$, d = 1.33) and Trial 4 ($F(1,264) = 4.77$, $p = 0.030$, d = 0.96), but were not in the last practice trial (Trial 5). Thus, the 3X practice-

Table 3. Comprehension Score Comparison (n = 47): Practice-Speed Groups in Trial 2; Note: ** = highly significant, * = significant, m = marginal difference

Trial 2—Comprehension Score

Practice-speed Comparison	***F*(1,264)**	***p***	**d**
1X vs. 2X	3.25	0.073^{m}	0.22
2X vs. 3X	3.35	0.069^{m}	0.23
1X vs. 3X	13.0	< 0.001**	0.44

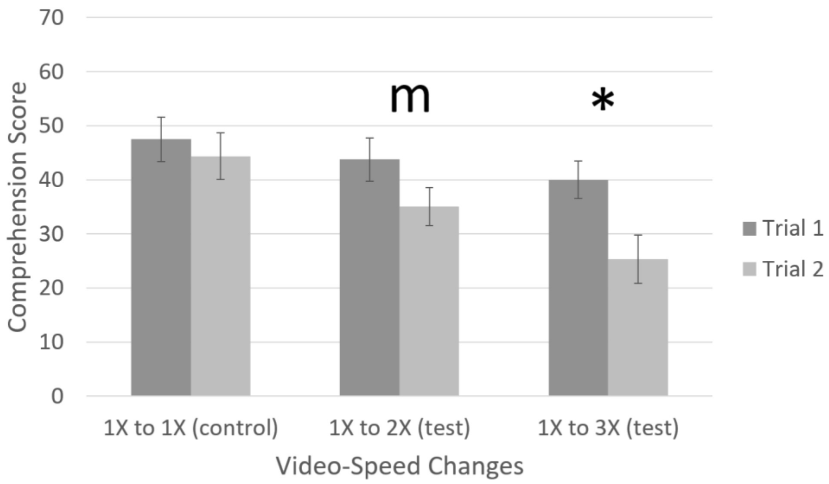

Fig. 5. Change in comprehension after video speed acceleration with no practice (Trial 1 to Trial 2) (n = 47). Note: * = significant difference, m = marginal difference. Error bars represent standard error.

speed group's comprehension of the videos sufficiently improved over time so that there was no significant difference between their comprehension and that of the 1X or 2X practice-speed groups' comprehension by the end of the practice trials (see Fig. 8).

5.2 Video-speed acceleration effect without practice

The difference between Trial 2 and Trial 1 within a group measures how acceleration affects comprehension when there is no practice at higher speeds. When participants moved from 1X (Trial 1) to 2X speed (Trial 2), a marginally significant decrease in comprehension occurred, $F(1,264) = 2.83$, $p = 0.094$, d = 0.21. When participants moved from 1X to 3X video speed, comprehension decreased significantly, $F(1,264) = 7.46$, $p = 0.007$, d = 0.34. In comparison, the 1X practice-speed group stayed at the 1X video speed for these two trials and had no significant change (see Fig. 5).

5.3 Video-speed acceleration effect with practice

The effect of video acceleration on comprehension when there are at least 7 minutes of practice at higher speeds is measured by subtracting Trial 6 from Trial 5 for each practice group. From Trial 5 (last practice trial) to Trial 6 (final trial, 3X), two of the participant groups increased in video speed. The 1X practice-speed group increased from 1X to 3X video speed, which led to a marginally significant decrease in comprehension score, $F(1,264) = 3.70$, $p = 0.056$, d = 0.24. The 2X practice-speed group increased from 2X to 3X video speed, which led to a significant decrease in comprehension score, $F(1,264) = 4.18$, $p = 0.042$, d = 0.25. In comparison, the 3X practice-speed group stayed the same at the

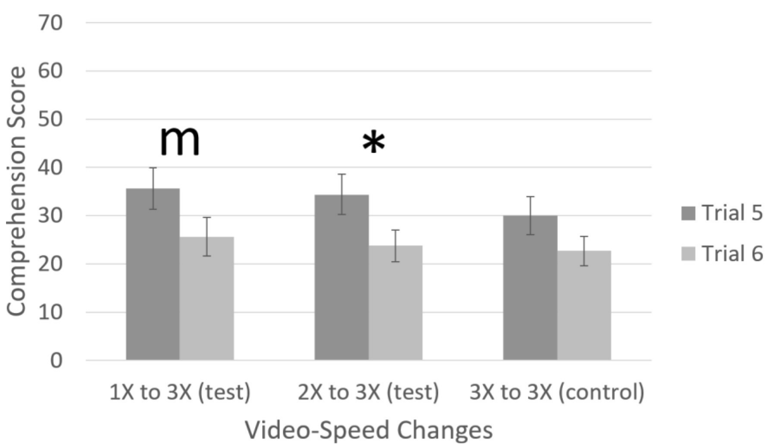

Fig. 6. Change in comprehension after video-speed acceleration with practice (Trial 5 to Trial 6) (n = 47). Note: * = significant difference, m = marginal difference. Error bars represent standard error.

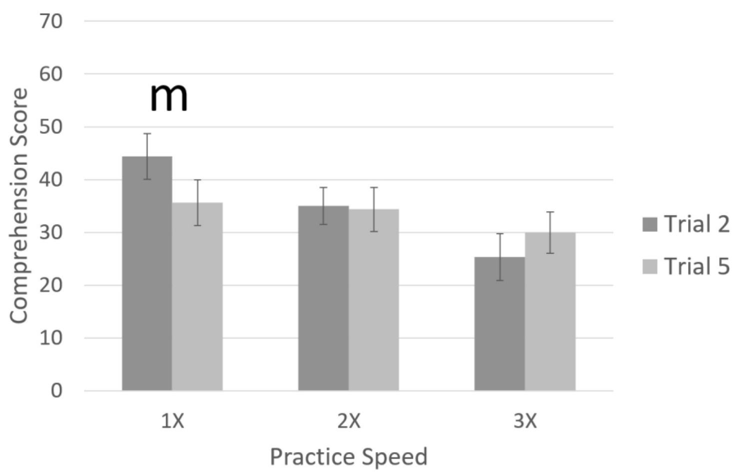

Fig. 7. Change in comprehension during practice trials (n = 47). Note: * = significant difference, m = marginal difference. Error bars represent standard error.

3X video speed for these two trials, and there was not a significant change in comprehension score (see Fig. 6).

5.4 Practice effect

The overall effect of practice at higher speeds can be measured by comparing the first time using a higher speed (Trial 2) and the last time at that same speed (Trial 5). The only effect that occurred within the practice-speed groups was that the 1X practice-speed group had a marginally significant decrease in comprehension between Trial 2 and Trial 5, $F(1,264) = 2.83$, $p = 0.094$, d = 0.21. For the 2X and 3X practice-speed groups, the change in comprehension between Trial 2 and Trial 5 was not significant. Figure 7 shows how the practice trials affected the different practice-speed groups' comprehension.

However, there was a convergence of comprehension scores between the three practice groups in Trial 5, seen in Fig. 8. In Trial 2, the practice-speed group was significant ($F(2,44) = 5.34$, $p = 0.008$), but in Trial 5, it was not significant.

5.5 Learning efficiency

The 2X practice-speed group had highly significantly ($F(1,185) = 34.4$, $p < 0.001$, d = 0.86) increased learning efficiency compared to the 1X practice-speed group across all four practice trials (see Fig. 9). The 3X practice-speed group also had highly significantly increased learning efficiency compared to the 1X practice-speed group ($F(1,185) = 57.0$, $p < 0.001$, d = 1.11). The 2X and 3X practice-speed groups were not significantly different in the first three practice trials, but the 3X practice-speed group did have significantly higher learning efficiciency compared to the 2X practice-speed group in the fourth practice trial, $F(1,176) = 5.59$, $p = 0.019$, d = 0.36.

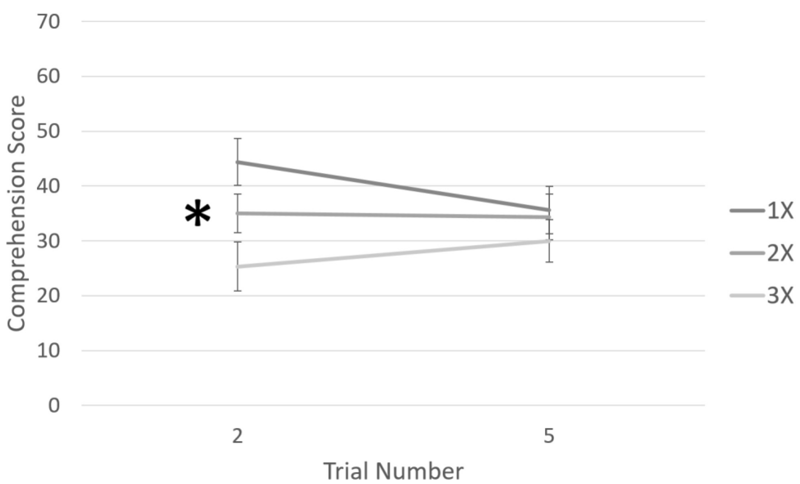

Fig. 8. Convergence of scores during practice trials. Note: * = significant difference, m = marginal difference (n = 47). Error bars represent standard error.

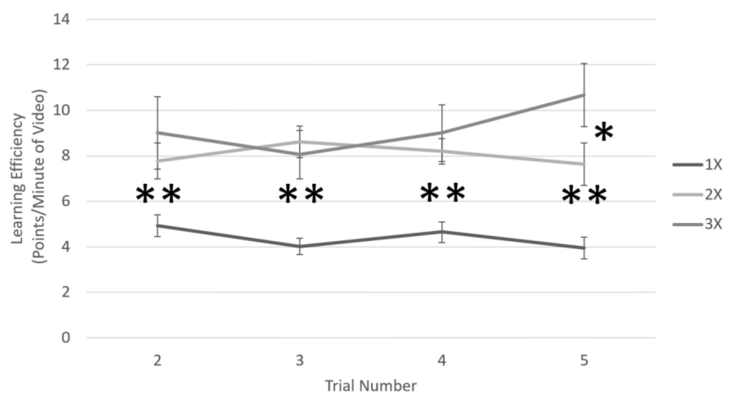

Fig. 9. Learning efficiency (comprehension points earned per minute of video watched) across 1X, 2X, and 3X practice speeds during practice trials (n = 47). Error bars represent standard error, ** denotes highly significant, * denotes significant difference.

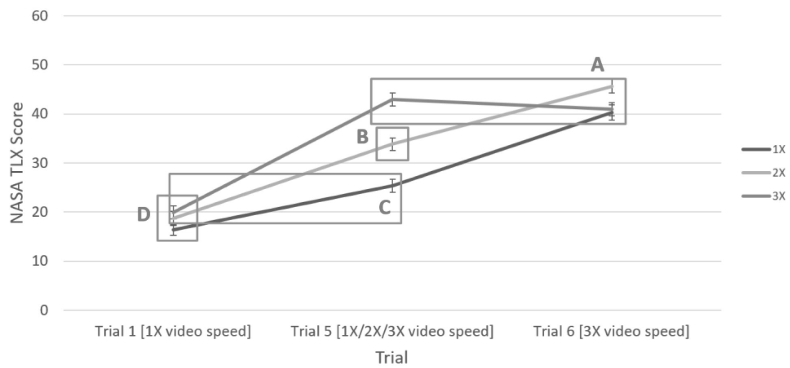

Fig. 10. NASA TLX average score and standard error across trials and video speeds. Note: Boxes represent workloads that are not significantly different (n = 47).

5.6 Cognitive workload

The results of the three different TLX surveys are seen across the three different practice speeds in Fig. 10. The results are for the overall workload score, which is the sum of the six TLX subscales.

The boxes in Fig. 10 group the values that are not significantly different. Box A shows that the workloads of watching videos at the 3X video speed were not significantly different. Box B surrounds the only point where the videos were watched at the 2X video speed. The 1X video speed was the only video speed that had significantly different workloads because it incorporates both Boxes C and D. The workload for the 1X practice-speed group in the last practice trial (T5) had a significantly ($F(1,132) = 9.41$, $p = 0.003$, d = 0.53) higher workload than the 1X practice-speed group in the baseline trial (T1).

6. Discussion

Hypothesis H1 was supported by the results. Without practice, comprehension decreased significantly or marginally significantly, and cognitive workload increased significantly as videos were accelerated by a factor of the normal speed. These results suggest that videos should not be accelerated to 2X normal speed or more if full comprehension is a top priority.

Hypothesis H2 was not supported. There is not enough evidence to support the hypothesis that 7 to 10.5 minutes of practice is sufficient to increase comprehension and preference at accelerated video speeds. Comprehension did not significantly increase with practice at accelerated speeds. During the practice trials, there were no significant increases in comprehension among any of the practice-speed groups. However, other effects within the practice trials were significant. In the first practice trial, the three practice groups' comprehension levels were significantly different, but at the end of the practice trials, none of the practice groups were significantly different. This convergence of the practice-speed groups' comprehension levels occurred because the 1X practice-speed group's comprehension level decreased, the 2X practice-speed group's comprehension level remained the same, and the 3X practice-speed group's comprehension increased.

This convergence could be due to a variety of reasons. First, the 1X practice-speed group spent two or three times as long watching videos (36 minutes) during the practice trials than the 2X (18 minutes total practice) and the 3X group (12 min), possibly leading to higher fatigue over time. Second, the accelerated videos may have caused the 2X and 3X students to consistently focus throughout the practice trials because the increased speed used all of their cognitive capacity, which did not allow for distracting thoughts. Third, the novelty of the accelerated video may have engaged the 2X and 3X practice-speed participants throughout the practice trials. Last, practice may have helped the 2X and 3X group comprehend the videos at the same or greater levels across the practice trials.

In the practice trials, the learning efficiency for participants was approximately double or more for the 2X and 3X video speeds compared to the 1X video speed. Acceleration at 2X video speed had a significantly higher learning efficiency than 1X video speed and significantly higher comprehension compared to 3X video speed. The 2X practice-speed group was also able to maintain its comprehension level, unlike the 1X practice-speed group whose comprehension level decreased marginally. Thus, 2X video speed is useful if time is a priority and full comprehension is not. However, it is important to note that 2X video speed is not a universal recommendation. While learning efficiency is important, maximum comprehension was obtained on the first comprehension quiz after watching the video at the 1X video speed. This demonstrates that if comprehension is the main goal, then it is important to watch videos at less than 2X video speed and take frequent breaks to reduce the effects of fatigue or boredom.

The study had several limitations. First, to keep the content the same, the three practice-speed groups had different amounts of time practicing during trials 2–5. The study did not explicitly measure for fatigue effects, which may have affected the performance of the 1X practice group, since they watched the four practice videos (Trials 2–5) for three times as long (average 36 min) as the 3X group (12 min) and twice as long as the 2X group (18 min). The results may be confounded with a fatigue effect for the 1X practice–speed group when compared to the accelerated groups. However, breaks were given to combat fatigue effects, and the longest overall time-watching period of 36 minutes was less than the average lecture. Further work is needed to clearly differentiate the positive gains of engagement with the negative effects of fatigue at different video watching lengths. Second, the study only looked at short term practice effects. Further work is needed to look at the sustainability of a practice effect over time. Third, given the number of participants, the study did not explore differential effects for subgroups of participants (e.g., age, gender, native English-speaking ability, grade-point average). Future studies could explore other factors that may impact comprehension under different levels of video acceleration. Fourth, the study only tested comprehension for concept explanation videos at a high-school or introductory college level. The results should not be extrapolated to different video types, such as videos where the student has to do the example along with the speaker, or to different difficulty levels, such as concepts or examples at an elementary or professional/expert level. Finally, future work is needed to test video acceleration's effect in an actual class setting to understand if the results generalize.

7. Conclusion

Two studies were conducted to understand the impact of various video viewing habits on learning and the implications for TBL in introductory engineering classes. Specifically, the preliminary study found that 75% of students in an introductory engineering course used the video lectures, with half of them watching at least two-thirds of the videos. Approximately 25–50% of the first-year industrial engineering students accelerated lecture videos, with 75% using 1.5X normal speed and 25% using 2X normal speed. The main study demonstrated that video acceleration beyond 2X significantly decreases comprehension. However, participants were able to accelerate videos up to 2X and with practice, able to maintain the same comprehension levels as participants watching at normal (1X) speed, whose comprehension levels decreased over time. Participants in the 3X group also showed some improvement, although not rising to the level of significance. Additionally, participants in the accelerated video groups did maintain comprehension levels for longer time periods than the control participants, demonstrating that engagement may be higher with video acceleration. However, the results suggest that there may be an interaction between the higher engagement of accelerated video and the fatigue of practice.

More research is needed on video acceleration, but based on these results, video acceleration seems useful for two reasons. First, students indicated that they appreciate the ability to accelerate the videos and that it helps them focus better. However, not all students used video acceleration, perhaps because they were not aware of the option, or felt that they risked lower comprehension with accelerated videos. Second, accelerating videos has higher learning efficiency, thus saving students' time, but with demonstrated impacts on comprehension. Students should be informed how practice at some speeds may help improve learning efficiency. Students need to be informed about learning options, have a good understanding of their own best learning methods, and consider practicing to improve their learning methods. Educators might want to consider recommendations about whether students should accelerate videos, or even accelerate the videos themselves prior to distribution. The learning goals, the complexity of the video, the motivation level of the students, and the video type will also affect whether accelerated video should be used. With the comprehension level needed in the TBL preparation phase, video acceleration below 2X normal speed could be effectively used by students. With the increase in learning efficiency that video acceleration allows, students could save significant time, allowing them to complete their coursework more efficiently. Increasing the effectiveness and efficiency of learning along with increased student engagement may positively affect retention in the engineering field during the early college years.

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