
Prof. Jim Kuo, California State University, Los Angeles

Jim Kuo is an Assistant Professor in the Department of Mechanical Engineering at California State University, Los Angeles. His current research is focused on renewable energy.

Mr. Justin Moon, California State University Los Angeles

Justin Moon earned a B.S. in Mechanical Engineering from U.C.L.A. in 2015. During his undergrad years, he developed a particular interest in the mathematical modeling of fluid dynamics and heat transfer. Currently, he is a second-year Master’s student in Mechanical Engineering at California State University Los Angeles. His current research focuses on heat transfer enhancements based on microchannel topology. Other research interests include Controls and H.V.A.C.R. systems. In his spare time, Justin likes travelling and exploring different cultures and cuisines.

Dr. Nancy Warter-Perez, California State University, Los Angeles

Nancy Warter-Perez is the chair of the Mechanical Engineering Department and professor of Electrical and Computer Engineering at California State University, Los Angeles.

Jim Kuo, Justin Moon, Nancy Warter-Perez
Department of Mechanical Engineering, California State University, Los Angeles

Background

This paper presents video analytics and assessment data on a recent effort to enhance student learning in a senior-level mechanical engineering course named ME 4061 (Heat Transfer I) at the California State University, Los Angeles (Cal State LA). ME 4061 is the final lecture course in the thermofluids course series and is a prerequisite to a final laboratory course in the series.

Thermofluids courses are math-intensive and make extensive use of physics and mathematics to describe physical systems. Furthermore, topics in ME 4061 Heat Transfer I involve concepts from two prerequisite thermofluids courses, Fluid Mechanics and Thermodynamics. Due to the challenging nature of the topics, ME 4061 had become a bottleneck course for many students.

In recent years, the mechanical engineering program at Cal State LA has experienced explosive growth in undergraduate enrollment, growing from 234 students in Fall 2007 to 890 students in Fall 2018\(^1,2\). This led to increases in class size and limited student interactions with faculty\(^3\). Furthermore, the majority of mechanical engineering students at Cal State LA come from socioeconomically disadvantaged families and are often the first in their families to attend college. Many hold part-time or full-time jobs to support their education and family. Their complex lives result in suboptimal learning environments and learning habits beyond the classroom. These multitudes of challenges often mean weaker academic preparation, which have unfavorably compounded as they progress through their studies. One particular observation is that students often rely on internet sources such as Chegg, YouTube, and discussion forums as their first source of information rather than textbooks, class notes, and instructors. However, there is significant variability in reliability as well as relevance of these online resources in relation to the contents taught in the classroom\(^4\).

On the other hand, engineering students are usually tech-savvy, and many already have been using online videos to supplement their learning. Past work on using videos to enhance student learning are plentiful and have shown to be effective\(^5,6,15,7-14\). Hence, the objective of the authors is to present topics in heat transfer through a platform familiar to students to improve student learning. In this work, YouTube videos are used to supplement existing course material, and YouTube analytics are used to study how these videos are used by students. The effectiveness of these videos is assessed from student performance on tests.

The questions to be explored based on the video analytics and student performance assessment data are: 1) What is a range of video length that would retain viewership? 2) What is an appropriate number of videos to improve student performance? 3) What type of videos are most effective – problem-solving or conceptual videos?
Course Organization

The Fall 2018 semester lecture course covered topics in conduction, convection, and radiation. The class met twice a week in two 75-minute sessions in traditional lecture format. Practice homework problems were assigned weekly but not collected for credit, and included both problem-solving and conceptual questions. Homework answers were provided along with the problem assignment, but the full solutions were not made available until the following week to encourage students to attempt the problems without solutions.

Although students did not receive credit for completing homework problems, competency in these practice problems was directly assessed through three noncumulative monthly tests and a comprehensive final exam. Each test (monthly tests and final exam, henceforth referred as tests) involved two parts, conceptual questions and problem-solving questions. Conceptual questions included definitions, derivations, and short answers, while problem-solving questions involved mathematical calculations. These test questions were directly drawn from the weekly homework, and students were reminded of this practice to encourage regular completion of homework. Furthermore, students were permitted to bring hand-written ‘cheat sheets’ to the tests, intended to force students to study and summarize course material.

In addition to practice homework, in-class problem-solving examples were frequently utilized in the classroom as active learning tools. It is well known that in-class problem-solving examples are effective educational tools as they provide detailed explanations of problem solutions\textsuperscript{16}. Thus, supplemental videos mimicking the problem-solving process would be very beneficial to students as the videos can be viewed and reviewed at any time for students to understand difficult ideas. The intention of creating supplemental videos is to improve the learning experience of these senior students with complex lives.

Initially these videos focused on solving selected homework problem-solving questions that are more challenging and conceptually important. Throughout the semester, the video content evolved to include conceptual discussions, and in length to mimic review lectures. Based on content, these videos can be broadly categorized into two types, problem-solving and conceptual. The effects of these changes were captured by the four tests, allowing preliminary comparisons of video design effectiveness.

Video Production and Publication

Video creation for supplemental course material can be a colossal effort, as the video planning process is an iterative process based on student feedback and performance. This section describes the software components leading to the mp4 file creation, as well as the required preparation time for each video.

Videos were recorded using Debut Video Capture and Screen Recorder Software from NCH. The software simply captures what appears on the computer screen and speech spoken through a computer microphone (Neewer NW-700 Condenser Microphone). Digital writing was done using an Intuos CTH-690 pen tablet and MS Paint. Finally, the recorded videos were edited used NCH’s VideoPad Video Editor.
All the videos were prepared by a graduate teaching assistant with significant tutoring experience. A snapshot of a sample problem-solving video is shown in Figure 1, which shows the use of Adobe Reader to illustrate the problem to be solved, and its solution digitally written side by side in MS Paint. Figure 2 shows a snapshot of a sample conceptual video, which has similar structure and layout to problem-solving videos. Each video includes an outline of topics covered, review of relevant prerequisite mathematical concepts, and examples related to specific course concepts. Emphasis was placed on dissecting each example by highlighting phrases and explaining their significance, as seen in Figure 1.

As the videos focused on selected homework problems in which solutions were made available to the students, video preparation time was minimized. The time it took to produce, edit and publish these videos on YouTube was approximately 1.5 to 3 times that of the video length. The production time decreased as the teaching assistant became familiar with the entire process. The effectiveness of the videos also will depend on the presenter’s oratory skills and succinct explanations.

Once the videos were published privately on a YouTube channel, their URL links were shared on the Canvas course site, meaning that the public cannot access the videos. There are many options to choose from in YouTube, and it is recommended that instructors experiment with these settings prior to publication.
Video Analytics

The purpose of the supplemental videos is to enhance learning through use of a platform familiar to students, permitting a natural learning process similar to students’ existing use of YouTube. One measure of success of engagement in these videos is viewer retention. Viewer retention is defined as the percentage length of a video that the viewers watched. For example, if someone watched 2 minutes of a 4-minute video, then the viewer retention is 50%. Viewer retention is used throughout this section to understand student behavior.

The schedule in which the videos were made available to students is shown in Table 1. Prior to Test 1, three short problem-solving videos less than 10 minutes were published, with a combined video length of 22 minutes. These three videos received very high viewer retention, >40% highlighted in grey, and is consistent with many YouTube publishers. Two of these videos received more views than the total number students in the class (>59 students) prior to Test 1, shown in red in Table 1. Note that the reason for the low number of views in the third video prior to Test 1 was due to a mistake in publishing the video URL on Canvas. However, those views increased significantly after Test 1, and all three videos received unique views (number of unique users viewing a video at the end of course) of more than 2/3 of the class size (>39 students), shown in blue in Table 1.
Table 1 – Information on heat transfer videos

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<th>Viewer Retention (% of Length)</th>
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<th>Views Prior to Test 2</th>
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* PS: problem-solving videos; C: conceptual videos
* Video title include the word ‘review’
* Grey: reviewer retention greater than 40%
* Red: video views prior to test is greater than class size (>59 students)
* Blue: unique views greater than 2/3 of class size (>39 students)
After receiving positive feedback from students, eight additional videos were made, totaling 1 hour and 40 minutes of video length, prior to Test 2. Seven of these videos were problem-solving videos, and one conceptual video, which focused on review of important concepts. However, only three of these eight videos received viewer retention of over 40%, and coincidentally were the shortest videos. The five remaining videos had viewer retention less than 31%. It is important to note that students may have watched the longer videos in multiple sessions. This explanation is supported by higher number of views despite similar numbers of unique views compared to the three videos with high viewer retention. Furthermore, six of these eight videos also received unique number of viewers greater than 2/3 of the class size. The title of the single conceptual video was deliberately named to include the word ‘review’ to elicit attention. As a result, nearly the entire class watched the video and it received significantly higher number of views than other videos.

Prior to Test 3, nine videos were published, all are relatively short videos, each less than 13 minutes, with very high viewer retention. The combined length of these videos is 1 hour and 27 minutes, similar to that of Test 2 videos. Six of these videos focused on concepts, while the remaining three focused on problem-solving. Seven of these videos were posted in week 12, one week prior to Test 3, and this timing seemed to have decreased the number of views and unique views in comparison to previous videos. However, seven of the nine videos received greater than 40% in viewer retention. There are two explanations, the first one is that the timing and number of videos created a ‘sense of urgency’ to pay attention. Another is the discussion nature of conceptual videos, unlike problem-solving videos, do not always require viewer’s undivided attention to the screen. Furthermore, three of these videos were named as ‘review’ and they also received higher viewership than others, consistent with previous results.

In preparation for the final exam, seven videos were posted including one problem-solving video and six lengthy review videos (ranging from 11 to 42 minutes) which included a mixture of problem-solving and conceptual questions from homework. The combined length of these videos is significantly higher than previous, totaling 2 hours and 34 minutes. It is interesting to note a distinct decrease in the number of views and unique views in accordance to publishing order as students tend to watch videos in sequential order. Looking at the high number of views and low number of unique views, it is clear that many students watched these videos in multiple sessions, leading to lower viewer retention for longer videos.

It is crucial to understand students’ viewing behavior in order to develop effective videos. This has been studied in the past, leading to the so-called ‘six minute rule’ for length of educational videos. There are also numerous online resources informing YouTube publishers to keep videos short to retain viewers, with some analysis pointing to ~5 minutes as the average length of YouTube videos as a guideline. Viewer retention of all supplemental videos are plotted against video length and is shown in Figure 3. Unsurprisingly, longer videos generally receive lower viewer retention. Note that no video longer than 16 minutes achieved over 40% viewer retention. When three-minute viewer retention and seven-minute viewer retention lines are plotted alongside the viewer retention data in Figure 3, it is clear that the viewer retention time for majority of the videos lie between three to seven minutes. Figure 4 shows video lengths and their corresponding viewer retention times, and it is clear that ~7 minutes seems to be the limit of student focus. However, this does not mean that longer videos are always undesirable, as data showed that students will take multiple sessions to complete the longer videos.
Figure 3 – Viewer retention vs. video length for all videos published.

Figure 4 – Video lengths compared with viewer retention times.
Assessment

The instructor had previously taught ME 4061 three consecutive semesters prior to Fall 2018 without video supplement. Thus, student performance from these three semesters can be used as a benchmark to quantify the effects of videos introduced in Fall 2018 semester. In each of the tests administered, one conceptual problem and one problem-solving problem were chosen for comparison with previous cohorts. The scores prior to Fall 2018 (total of 98 students pre-video) were aggregated and used as a benchmark to compare to the Fall 2018 results (59 students post-video).

Student performance on these assessment problems were categorized in letter grades of A, B, C, D, F. The authors are interested in whether the supplemental videos are effective in reducing the proportion of low performing students with D or F grades, as well as increasing the proportion of high performing students with A or B grades. Note that a C grade is neither ‘good’ nor ‘bad’ and are not directly used in this assessment, but it is indirectly captured when comparing percentage share of students attaining A or B grades, and D or F grades. Comparisons were done using the pre-video results as benchmark of percentage share of pre-video students achieving A or B grades, D or F, and F only grades. Post-video results of students achieving A or B grades, D or F, and F only grades as percentage share of post-video students were compared to pre-video results. Changes in percentage shares are obtained by subtracting post-video percentage shares with that of pre-video benchmark percentage shares. Changes in percentage share greater than 5% or less than -5% are considered to be significant. This was chosen as the Fall 2018 class had 59 students, thus any positive or negative changes less than three students from this small sample size could be attributed to chance. For example, if 30% of students prior to Fall 2018 achieved a grade of A or B, and 40% of students achieved a grade of A or B in Fall 2018, then the change in percentage share of students is +10%, which is a significant change indicating videos have a positive effect.

Figures 5, 6, and 7 show the changes in percentage share of students achieving grades of A or B, D or F, and F only in problem-solving questions on the four tests. For Test 1, the videos decreased the share of students (10%) achieving grades A or B and increased the share of students (18%) achieving D or F and F only for problem-solving questions. Although many students had responded that the videos were very useful, some students mentioned that they had focused too much on the videos and neglected to study other course materials. However, in Test 2, positive effects were seen with 13% increase in percentage share of the class achieving A or B. Positive effects were seen from the lower performing end as well, with 18% and 15% decreases in share of the class achieving D or F, and F only, respectively. For Test 3, there were no significant changes in results in terms of problem-solving performance as most of the videos posted were conceptual videos. For the final exam, there were no significant changes in shares of students achieving grades of A or B and D or F, but a decrease 7% of the class achieved F grade was observed.
Figure 5 – Change in percentage share of students achieving a grade of A or B in problem-solving. Red shows a decrease in share (negative effect), green shows an increase in share (positive effect), and grey shows negligible change in share (ineffective).

Figure 6 – Change in percentage share of students achieving a grade of D or F in problem-solving. Red shows an increase in share (negative effect), green shows a decrease in share (positive effect), and grey shows negligible change in share (ineffective).
Similarly, Figures 8, 9, and 10 show the changes in percentage share of students achieving grades of A or B, D or F, and F only in conceptual questions on the 4 tests. In Test 1, even in the absence of conceptual videos, there was an 18% increase in share of students achieving grades of A or B, an 18% decrease in share of students achieving grades of D or F, and a 14% decrease for grades of F only. These positive results are remarkable as the three videos posted focused on problem-solving. However, it is known that problem-solving examples are effective in conveying underlying principles, allowing students to relate concepts to actual problems to further reinforce understanding of conceptual ideas\textsuperscript{23}. These positive results are also echoed in Test 2 results (seven problem-solving and one conceptual videos), where a 19% increase in share of students achieving grades of A or B and a 12% decrease in share of students achieving grades D or F were seen. Even more impressive is the 17% decrease in share of students achieving a grade F.

In Test 3, the results are mixed, with a 16% increase in share of students achieving grades A or B and negligible change in D or F grades. However, an unexpected 7% increase in share of students achieving a grade of F was seen. This was surprising as Test 3 preparation videos focused mainly on conceptual videos. It is noteworthy that the instructor had shared the test questions with the graduate student assistant producing the videos and this may have unintentionally affected the video content, particularly the conceptual review videos. As a result, the instructor had observed that many students used the concept videos to construct cheat sheets rather than constructing their own using class notes and textbooks. Furthermore, due to the higher number of videos, some students assumed that the videos are comprehensive in nature and became overreliant on them. The format of the conceptual videos seemed to have been ineffective and may even have impeded deeper conceptual learning of weaker students.
Figure 8 – Change in percentage share of students achieving a grade of A or B in conceptual problems. Red shows a decrease in share (negative effect), green shows an increase in share (positive effect), and grey shows negligible change in share (ineffective).

Figure 9 – Change in percentage share of students achieving a grade of D or F in conceptual problems. Red shows an increase in share (negative effect), green shows a decrease in share (positive effect), and grey shows negligible change in share (ineffective).
In the final exam, a 35% decrease in share of students achieving grades A or B was observed, and there were increases of 14% and 11% in share of students achieving grades D or F, or F only, respectively. These negative results show that the lengthy video format is not effective in conceptual preparation, and that they took away time and effort that could have been spent on other course materials. Students also have noted exhaustion and stress as a result of lengthy videos and ‘longer than usual’ combined video length.

Overall, the eight videos prior to Test 2 seems to produce highest improvements in student performance, which included seven problem-solving videos and one conceptual video over the course of four weeks. In terms of frequency of videos, one to two videos a week seems to be effective. This is likely due to the fact most of video views occur days before the tests and a large quantity of videos may overwhelm students. Even when the number of videos is as low as three problem-solving videos in four weeks, some positive effects on conceptual understanding were observed. However, this low frequency of problem-solving videos seemed to have negative effects on problem-solving as students assumed that test problems to be similar to those presented in the videos. Instructors should make sure that students are fully aware that these problem-solving videos are simply supplemental to existing course material, otherwise students may mistaken the videos to be representative and comprehensive of testing material.

This work set out to explore the three questions stated earlier: 1) What is a range of video length that would retain viewership? 2) What is an appropriate number of videos to improve student performance? 3) What type of videos are most effective – problem-solving or conceptual videos?
Based on preliminary video analytics of one course offering, it was found that a video length between three to seven minutes would be effective in retaining viewers; however, this does not mean longer videos are always undesirable as students will watch longer videos over multiple sessions. Occasional >15-minute videos titled ‘Test Review’ can help retain the attention of many students. At the same time, students can be easily overwhelmed with large numbers of videos, no matter how short they are. After all, these videos are meant to be supplemental and not the primary material. Preliminary data suggest that one to two videos per week with a combined length of ~15 minutes is effective and sustainable from perspectives of both the instructor and students.

Instructors should be aware that videos can affect student studying habits, positively and negatively. Based on current work, high number of conceptual videos seemed to have negative effects on student performance. One observation is that many students became overreliant on videos and did not develop coherent self-explanations of underlying principles using all available course content (e.g. course notes, textbook). It is recommended that instructors focus most of the video-making effort on problem-solving videos as they are shown to be effective in illustrating concepts and principles in every step, enabling students to connect abstract ideas with practical examples16,23.

Future Work

The authors are committed to improving the quality of the videos, and will continue to revise them. This includes developing videos illustrating the most challenging concepts using experimental demonstrations and digital arts that are typically difficult to achieve in lecture classrooms.

The authors plan to continue collecting data on the effectiveness of supplemental videos in future offerings of the course, include other instructors to broaden the study, and to develop strategies to influence students’ studying habits. In addition, longer term effects of the current videos will be assessed. The authors intend to track and analyze post-video student performance in the subsequent laboratory course, and compare with students without videos in ME 4061.

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