Impact of Topic and Video-Based Learning in Programming on Students' Performance: A Pilot Study in Undergraduate Engineering Education

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Abstract
This pilot study addresses the effectiveness of different teaching materials on engineering students' learning outcomes through a dual-sectioned approach. 38 participants were administered a pretest and posttest for each of two different topics; This means a total of 76 reviews. Paired two-sample t-test analysis showed a statistically significant increase in performance scores, meaning students showed significant improvement when interacting with instructional materials. Performance scores significantly exceeded scores associated with material use, indicating that instructional content plays an important role in learning success. A notable positive t-statistic suggests that these improvements cannot be due to chance and highlights the effectiveness of the materials in improving educational outcomes. The significance of these results has led to a re-evaluation of material selection processes in engineering education, showing that they are powerful variables in optimizing student performance. In conclusion, this study paves the way for subsequent research on learning methods aimed at establishing evidence-based practices for advanced pedagogical strategies in engineering disciplines.

Keywords*:* Video-Based Learning, Programming, Software Engineering Education, Experiment

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Introduction

In the changing world of engineering education, the integration of technology, particularly video-based learning (VBL), has become a crucial component of innovative teaching methods. This adoption of technology driven learning approaches has proven to have an influence on student outcomes by providing a dynamic and interactive educational experience. Noetel et al. (2021) conducted a study on the effectiveness of video in education highlighting its potential to either replace or complement traditional teaching methods and enhance learning results (Noetel et al 2021).

Despite the research conducted on VBL there are still gaps in its implementation and effectiveness in areas, such as engineering education. Culajara's (2023) research on using video-based presentations in education displays the advantages of VBL in enhancing student engagement and performance suggesting its applicability in broader educational contexts (Culajara, 2023). Furthermore Ghilay (2021) emphasizes the significance of integrating high quality videos with text to enhance learning experiences within quantitative courses.

To address these gaps this study seeks to investigate how different instructional materials, within VBL environments impact student learning outcomes in engineering education. According to research conducted by Valero Laparra et al. (2023) on how students engage with video content it appears that using videos has an impact on performance. Moreover, Nadeak and Naibaho (2020), back the notion that incorporating video-based learning environments can enhance students learning achievements in challenging subjects.

By filling these gaps, this study contributes to a deeper understanding of VBL's role in engineering education. Provides insight into the design and implementation of effective VBL strategies by investigating how a variety of video materials impact student performance and engagement. This research enriches academic discourse and provides a foundation that can underpin practical implications for educators in optimizing student learning outcomes through technology-enhanced educational content.

Related Work

The emergence of video-based learning (VBL) in engineering education marks a significant shift towards the adoption of technology-enhanced learning methods. Research increasingly highlights the increasing role of technology in education and highlights the potential of technology to transform traditional pedagogical approaches. Especially in engineering education, where complex concepts and practical applications are crucial, VBL offers an innovative way to increase students' understanding and engagement.

(Noetel et al.'s 2021) systematic literature review underscores this transformation by revealing that video integration as a replacement or complement to traditional teaching methods leads to improved student learning outcomes. This finding is particularly relevant to engineering education, where visual and interactive content can significantly aid the understanding of complex theoretical concepts and practical procedures. Moreover, the study conducted during emergency distance learning in electrical engineering [6] demonstrates the effectiveness of didactic videos in maintaining educational quality and student interest even in challenging learning scenarios (e.g. COVID). Collectively, these studies highlight the growing importance of VBL in engineering education, pointing to an important step towards more interactive and technologically integrated teaching methodologies, and that this step is inevitable.

Existing research on Video Based Learning (VBL) in various educational contexts and branches highlights its effectiveness in increasing student engagement and performance with different studies and different constructs. Studies such as the study conducted by Bernadetha Nadeak and Lamhot Naibaho [5], focusing on Anatomy Practice, have found significant improvements in student learning outcomes with the use of VBL. Similarly, (Carla Jobelle Culajara, 2023)'s research in physical education showed that video-based presentations significantly increased learning performance, demonstrating the versatility of VBL across different disciplines. Moreover, Meehyun Yoon, Jungeun Lee, and Il-Hyun Jo's work on video learning analytics (2021) offered perspective on behavioral patterns in video-based online learning, pointing to various student engagement styles, that is, individual differences in students' learning. This research highlights the adaptability of VBL to address a variety of learning preferences, thereby improving educational outcomes across multiple learning environments.

While existing studies have demonstrated the effectiveness of VBL in various educational contexts, there remain gaps in the literature, particularly regarding its application and effectiveness in engineering education. Most research has concentrated on the impact of VBL on student engagement and performance in general education or specific subjects like Anatomy and Physical Education. However, there is a relative dearth of comprehensive studies focusing exclusively on engineering education. Addressing this gap is important to tailor VBL strategies to the specific needs of engineering education and maximize their potential benefits.

Comparative analysis of the studies reveals a diverse range of methodologies, populations, and educational contexts. For instance, Noetel et al.'s systematic review encompassed randomized trials in higher education, offering a broad perspective on VBL across various disciplines. Contrastingly, Bernadetha Nadeak and Lamhot Naibaho's study employed classroom action research, focusing specifically on Anatomy, demonstrating the effectiveness of VBL in detailed, subject-specific learning. Similarly, Carla Jobelle Culajara's research in physical education utilized a mixed-method approach, highlighting how VBL can enhance learning in more practical and physical domains. Meehyun Yoon, Jungeun Lee, and Il-Hyun Jo's study on video learning analytics delved into online learning environments, focusing on behavioral patterns and learner engagement styles. These varied approaches underscore the adaptability of VBL across different educational settings and learning styles, although they also indicate a need for more targeted research in specific fields like engineering education.

The significance of video quality and its integration with other learning materials is a critical aspect in the effectiveness of VBL. Ghilay's study on the Text-Based Video (TBV) model (Ghilay, 2021) highlights the importance of combining high-quality videos with textual content to enhance understanding and engagement, particularly in subjects like mathematics. This suggests that the integration of multiple learning modalities can significantly improve learning outcomes. However, there is a lack of comprehensive research specifically focusing on the impact of video quality, such as resolution, production value, and content clarity, on student learning in engineering education. This area presents an opportunity for further exploration to optimize VBL strategies for education.

The studies reviewed often implicitly or explicitly utilize various theoretical frameworks, especially those related to multimedia learning. For instance, the systematic review by (Noetel et al. 2021) aligns with Mayer's Principles of Multimedia Learning, which emphasize the cognitive processes involved in learning through multimedia resources. The focus on integrating text with videos in Ghilay's study (Ghilay, 2021) reflects Dual Coding Theory, suggesting that textual and visual information processed in separate channels can enhance learning. However, a gap in the current literature is the explicit discussion of these theoretical frameworks in the context of engineering education. Future research could benefit from a more direct application of these theories to understand how they can be effectively implemented in engineering-focused VBL strategies.

The studies reveal strengths such as different methodologies and contexts, demonstrating the broad applicability of VBL. For instance, Noetel et al.'s (2021) systematic review offers a comprehensive overview of the field. However, a potential weakness across studies is the lack of deep focus on specific disciplines like engineering education, which may limit the applicability of findings to this field. Additionally, while studies like Ghilay's integrate multiple learning modalities, there's a general lack of emphasis on the role of video quality and its impact on learning outcomes. Another concern is the potential bias in participant selection and the context of the studies, as most research tends to focus on short-term impacts rather than long-term retention and applicability in diverse educational settings. Future research should aim to address these gaps and biases to provide a more comprehensive understanding of VBL in specific educational disciplines.

This study shows some gaps in current research by investigating the impact of different instructional materials in VBL environments on student learning outcomes in engineering education. It provides new insights into how various video materials affect student performance and engagement, enriching academic discourse and offering practical implications for educators in optimizing student learning outcomes through technology-enhanced educational content. This approach aligns well with the identified research gaps and offers valuable contributions to the field of VBL in engineering education. It sheds light on the success of VBL in different disciplines, that is, in different subjects, and its specific applicability in different subjects in the field of engineering.

Research Hypotheses

In this study, we designed and implemented a pilot experiment to examine the impact of topic on individual students' learning performance in video-based learning. Each hypothesis contains one independent variable which is abbreviated in parenthesis at the end of description. The dependent variable in all hypotheses is the student's learning performance. We do not include the alternative hypotheses here and only present the null hypotheses): In the experiment, we have tested the following hypotheses:

$H1_0$: Individual student's learning performance in programming is not impacted by the topic used (t).

$H2_0$: Individual student's learning performance in programming is not impacted by video-based learning (VBL).

In our model there are two independent and one dependent variable. The dependent variable is the individual student's learning performance (delta), while topic (t) and video-based learning (VBL) are the dependent variables.

Figure 1 presents the hypothetical model used in the study.

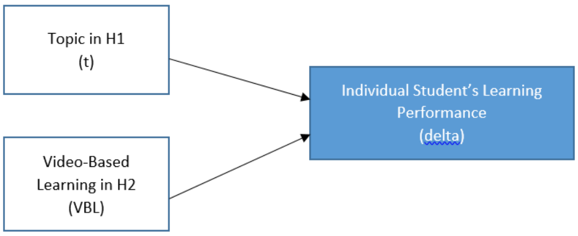

Figure 1: Hypothetical Model

Methodology

To investigate the hypotheses listed in Section III, we designed and conducted an experiment as part of a pilot study that is implemented within the scope of an undergraduate programming course named as: Fundamentals of Programming II.

A. Population and Sample

All 104 students enrolled into the course have been invited to the experiment. The researchers clearly stated that the privacy and confidentiality of the individual students' related data will be preserved. Due to time conflicts, not all students were able to attend the experiment. Out of 104 total, 78 students participated in the experiment. Prior to the experiment, it had been announced that the participants of the experiment would earn a 1% bonus if they actively took part in the experiment.

B. Experiment Design

In the beginning of the experiment, we delivered a brief introduction related to experiment execution. We selected "Exceptions" and "Recursion" as the topics to be learned by the student participants. We preferred these two topics because they were not studied in the lecture previously.

The students were divided equally into two groups based on their performance in the course's first Midterm exam. For each group a pre-test was given on one topic, followed by a video teaching the topic and a post-test. On one topic, all of the questions in the pre-tests and post-tests are the same. The students could submit test results only once. It was mandatory to provide answers to all questions in the tests.

The videos teaching the topics included related content and a subset of questions in these tests. The videos were played by a single computer connected to the projector in the classrooms.

Figure 2 presents the order of material used and duration of the experiment steps for different groups.

C. Experiment Material

For each topic related to programming in Java language, the instructor of the course, and one of the authors of the study created two videos and two presentations. In addition, she prepared a pre-test and a post-test for each of the topics.

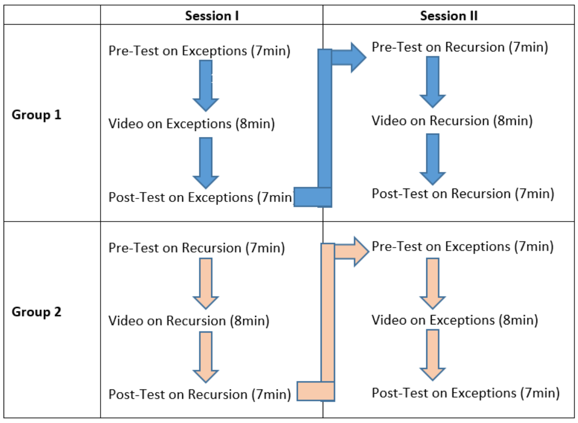

Figure 2: Order of Topics and Material Used in the Experiment

D. Review of Materials

Prepared materials have been reviewed by the other two authors, one of them being the teaching assistant of the programming course. Suggested revisions were reflected to the material and they were finalized before the experiment.

E. Data Cleaning and Analysis

Every participant student is expected to complete four tests. After the experiment, we realized that two of the students did not answer all of the tests, as a result, we decided to remove data of these two participants. Hence, valid data was collected from 76 participants. One of the authors coded the collected data for them to be analyzed. The coded data in MS Excel worksheets were then used by two authors, one of them used IBM SPSS and the other used MS Excel to perform data analysis.

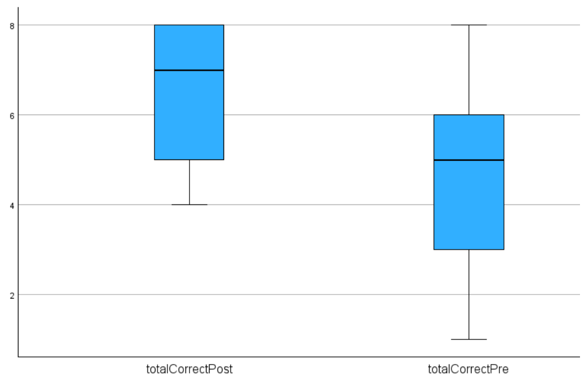

Figure 3: BoxPlot Total Correct Answers Post-test and Pretest

As it can be seen in Figure 3, there is an observable difference between the total number of correct answers given in the post test and that of in the pretest. Paired sample t-test has been used in repeated-measures designs where the same subjects are measured multiple times. This is common in experimental designs where testing the effect of time or a condition on the same group of subjects.

When the data is grouped according to the material topic (subject), the box plot in Figure4 shows that the participants provided more correct answers in the post test for topic Recursion, denoted by R, than topic Exceptions, represented by E.

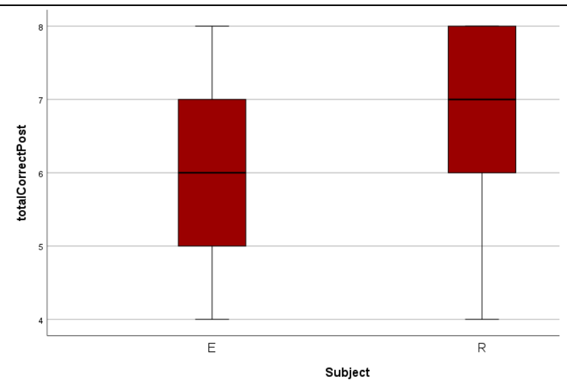

Figure 4: Boxplot for Post test correct answers grouped on Topic

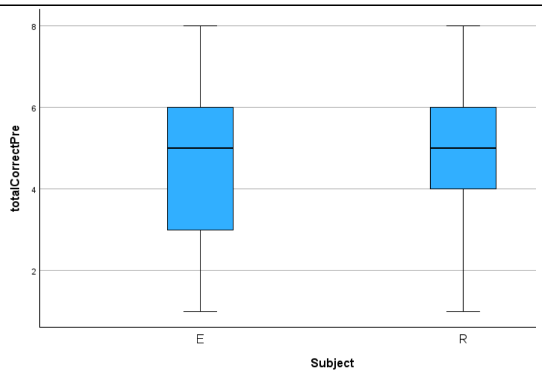

Figure 5: Boxplot for Post test correct answers grouped on Topic

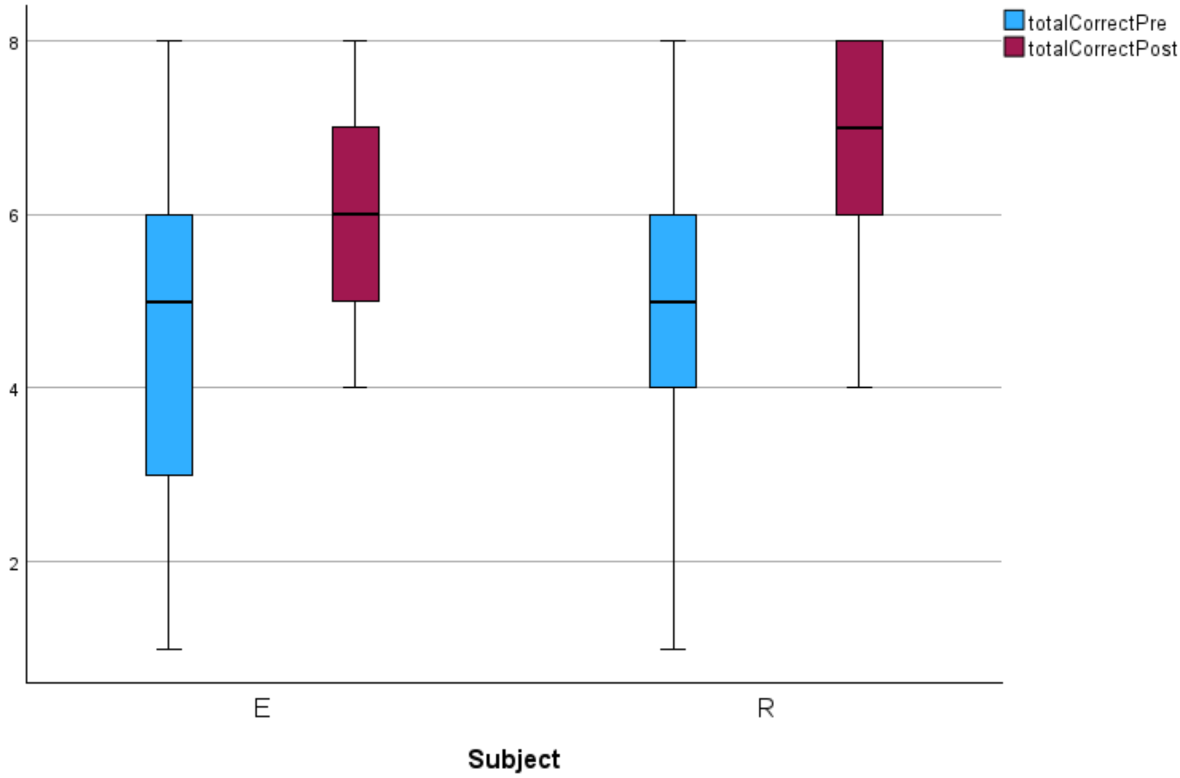

Figure 6: Boxplot for Pretest correct answers grouped on Topic

Paired sample proportions are conducted where success was defined as 7 and 8. Finally, openAI.com ChatGPT was used for interpreting results obtained from the statistical tests.

Results

The results of the paired sample t-tests are provided by Table 1.

Subject denotes topic and delta refers to the performance change in between post and pretests correct results belonging to individual students. Mean: The mean of 'delta' is approximately 1.76, and the mean of 'Subject' is 0.50.

Standard Deviation: 'delta' has a standard deviation of approximately 1.773, which indicates variability around the mean, and 'Subject' has a standard deviation of 0.503.

Paired Samples Correlations:

Correlation: There is a Pearson correlation coefficient of 0.149 between 'delta' and 'Subject', suggesting a weak positive relationship.

Significance: The one-sided p-value is 0.099, and the two-sided p-value is 0.198, which are not statistically significant if we consider a common alpha level of 0.05.

A. Paired Samples Test

Paired Differences: The mean difference between 'delta' and 'Subject' is 1.263.

Standard Error of Mean: The standard error is 0.203, which gives an idea of the precision of the mean difference estimate.

95% Confidence Interval of the Difference: The lower bound is 0.859, and the upper bound is 1.667, which means we can be 95% confident that the true mean difference lies within this range.

t Statistic: The t-statistic is 6.224, which is a measure of how many standard errors the mean difference is away from zero.

Degrees of Freedom (df): The degrees of freedom for the test is 75.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	delta	1,76	76	1,773	,203
	subject	,50	76	,503	,058

Paired Samples Correlations

				Significance	
		N	Correlation	One-Sided p	Two-Sided p
Pair 1	delta & subject	76	,149	,099	,198

Paired Samples Test

		Paired Differences							Significance	
					95% Confidence Interval of the Difference					
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	One-Sided p	Two-Sided p
Pair 1	delta - subject	1,263	1,769	,203	,859	1,667	6,224	75	<,001	<,001

Paired Samples Effect Sizes

					95% Confidence Interval	
			Standardizer[a]	Point Estimate	Lower	Upper
Pair 1	delta - subject	Cohen's d	1,769	,714	,460	,964
		Hedges' correction	1,787	,707	,455	,955

a. The denominator used in estimating the effect sizes.
Cohen's d uses the sample standard deviation of the mean difference.
Hedges' correction uses the sample standard deviation of the mean difference, plus a correction factor.

Table 1: Paired Samples t- test Results

B. Paired Samples Proportions Test

Paired-Samples Proportions Statistics

		Successes	Trials	Proportion	Asymptotic Standard Error
Pair 1	totalCorrectPost = 7, 8	41	76	,539	,078
	totalCorrectPre = 7, 8	14	76	,184	,104

Paired-Samples Proportions Confidence Intervals

				95% Confidence Interval of the Difference	
	Interval Type	Difference in Proportions	Asymptotic Standard Error	Lower	Upper
Pair 1: totalCorrectPost - totalCorrectPre	Bonett-Price	,355	,061	,224	,468
	Newcombe	,355	,061	,226	,467
	Wald	,355	,061	,236	,475

Paired-Samples Proportions Tests

					Significance	
	Test Type	Difference in Proportions	Asymptotic Standard Error	Z	One-Sided p	Two-Sided p
Pair 1: totalCorrectPost - totalCorrectPre	Mid-p Adjusted Binomial	,355	,061		<,001	<,001
	McNemar	,355	,061	4,849	<,001	<,001

Table 2: Paired Samples Proportions Statistics Results

Successes Pre: Before the intervention (or in the first condition), there were 14 successes.

Successes Post: After the intervention (or in the second condition), there were 41 successes.

Trials: There were 76 trials in total for both conditions.

Proportion Pre: The proportion of successes pre-intervention is 0.184.

Proportion Post: The proportion of successes post-intervention is 0.539.

Asymptotic Standard Error: The standard error associated with the difference in proportions is 0.078.

Paired-Samples Proportions Confidence Intervals

Difference in Proportions: The observed difference in proportions between the pre and post conditions is 0.355.

95% Confidence Interval of the Difference: The confidence intervals for the difference in proportions have lower bounds ranging from 0.224 to 0.236 and upper bounds from 0.467 to 0.475, depending on the method (Bonett-Price, Newcombe, or Wald). This indicates a high level of confidence that the true difference in proportions lies within these ranges.

Paired-Samples Proportions Tests

McNemar Test:

Asymptotic Standard Error: The standard error for the McNemar test is 0.061.
Z: The z-value for the McNemar test is 4.849, which is a measure of how many standard errors the observed difference is away from zero.

Significance: Both one-sided and two-sided p-values are less than 0.001, indicating a statistically significant difference in proportions from the pre to post conditions.

The results of the proportion paried samples test is provided in Table 2.

Discussion

According to the paired sample t-test, the paired samples t-test indicates that there is a statistically significant difference between the means of 'delta' and 'Subject', with 'delta' being higher on average. The effect size measures (Cohen's d and Hedges' g) suggest that this difference is not only statistically significant but also of a moderate to large magnitude.

The test's statistical significance ($p < 0.001$) strongly suggests that the material represented by 'Subject' has a significant impact on the performance outcomes measured by 'delta'. The results indicate that changes in 'Subject' are associated with substantial changes in 'delta', which could be interpreted as the material having a considerable effect on performance.

The confidence interval for the mean difference does not include zero, which reinforces the conclusion that there is a significant effect. However, the Pearson correlation is relatively low, indicating that while the two variables are related, the relationship is not very strong.

Based on the proportion's tests, the paired-samples proportions test shows a significant increase in the proportion of successes from the pre-condition (around 18.4%) to the post condition (around 53.9%). The 95% confidence intervals are well above zero and do not overlap with it, which supports the significance of the increase in successes.

The McNemar test confirms the significance of this finding, with a very large z-value and p-values far below the conventional threshold of 0.05 ($p < 0.001$ for both one-sided and two-sided tests). This strongly suggests that the intervention or condition change had a significant effect on the proportion of successes.

Threats to Validity and Limitations

One of the authors also performing the experiment is the instructor of the course. The researcher bias that may stem from this fact is avoided via analysis conducted by two researchers independently and comparing the analysis results. Two reviewers who are experts on material and experimental design in computer education investigated the materials and design.

The pilot has been conducted in one course can the results obtained cannot be generalized.

Some students have taken this course previously. By measuring the performance as a difference is posttest and pretest this limitation is mitigated.

The videos are not played by the participants, rather a single computer is used to play the video and a projector is used, allowing all participants in a classroom to watch the videos at the same time from a single source.

Conclusion and Future Work

Overall, we can conclude that according to the data provided, 'Subject' (topic, t) has a significant impact on 'delta', which in the context of your experiment suggests that the choice of material significantly affects performance.

The results of the proportions test indicate that there was a substantial and statistically significant improvement associated with the post condition compared to the pre-condition in the variable being measured. This provides strong evidence that whatever change was implemented between the two measurements had a positive impact on the outcome. The change was the video-based learning material utilization. Thus, VBL has a positive impact on the learning performance.

For future work, we plan to conduct the experiment with more students using different materials and courses. Pilot experiment's data and the materials will be anonymously available to the researchers willing to conduct further studies.

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