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From rote learning to deep learning: Filling the gap by enhancing engineering students' reasoning skills through explanatory learning activities

Dr. Huihui Qi, University of California San Diego

Dr.Huihui Qi is a Teaching Assistant Professor at the University of California, San Diego.

Minju Kim, University of California San Diego

Minju Kim is a postdoctoral scholar at the Engaged Teaching Hub at the UCSD Teaching+Learning Commons. Minju received her Ph.D in Experimental Psychology at UC San Diego. With Engaged Teaching Hub, Minju has designed TA training materials for oral exams and have conducted quantitative analysis on the value of oral exams as early diagnostic tool (Kim et al., ASEE 2022). Minju is interested in designing assessments that can capture and motivate students' deep conceptual learning, such as oral exams and the usage of visual representations (e.g., diagrams and manual gestures).

Yu Li, University of California San Diego

Brian has received his Master of Science degree in material science. He is currently continuing his education as a Material Science Ph.D. student. As a graduate student, Brian has spent the past three years as a teaching assistant in a variety of undergraduate courses. His research background focuses on medical devices and soft composite development.

Dr. Carolyn L. Sandoval, University of California, San Diego

Dr. Sandoval is the Associate Director of the Teaching + Learning Commons at the University of California, San Diego. She earned a PhD in Adult Education-Human Resource Development. Her research interests include adult learning and development, faculty de

Prof. Curt Schurgers, University of California San Diego

Curt Schurgers is a Teaching Professor in the UCSD Electrical and Computer Engineering Department. His research and teaching are focused on course redesign, active learning, and project-based learning. He also co-directs a hands-on undergraduate research program called Engineers for Exploration, in which students apply their engineering knowledge to problems in exploration and conservation.

Marko V. Lubarda, University of California San Diego

Marko V. Lubarda is an Assistant Teaching Professor in the Department of Mechanical and Aerospace Engineering at the University of California, San Diego. He teaches mechanics, materials science, design, computational analysis, and engineering mathematics courses, and has co-authored the undergraduate textbook Intermediate Solid Mechanics (Cambridge University Press, 2020). He is dedicated to engineering pedagogy and enriching students' learning experiences through teaching innovations, curriculum design, and support of undergraduate student research.

Xuan Emily Gedney

Dr. Saharnaz Baghdadchi, University of California San Diego

Saharnaz Baghdadchi is an Assistant Teaching Professor at UC San Diego. She is interested in scholarly teaching and uses active learning techniques to help students achieve an expert-like level of thinking. She guides students in bridging the gap between facts and usable knowledge to solve complex engineering problems.

Dr. Alex Phan, University of California San Diego

Dr. Phan received his Ph.D. in Mechanical Engineering from the University of California San Diego with a specialization in medical devices. He is currently an instructor for the Department of Electrical and Computer Engineering focusing on hands-on education.

From rote learning to deep learning: filling the gap by enhancing engineering students' reasoning skills through explanatory learning activities

Abstract

Rote learning refers to the superficial learning of concepts and procedures, typically by brute memorization and with little integration into existing cognitive schemas, resulting in poor knowledge retention and inability to apply the knowledge in new and evolving contexts. With rote learning, students usually learn declarative and procedural knowledge but usually do not pay attention to conditional knowledge (when to use what knowledge). As a result, they usually can replicate the problem-solving process in a familiar context but are unable to transfer the knowledge and use the concept for a new application.

This paper explores the use of explanatory learning activities to promote students' deep learning. Cognitive psychology literature shows that students do not necessarily learn concepts deeply by solving problems, unless they monitor their thinking and decision-making process before and during problem solving, and reflect on the process after will help to conditionalize their knowledge, i.e., when to use what knowledge to solve the problem.

In this paper, we present a study on a multidimensional approach to enhancing students' reasoning skills by integrating a variety of explanatory learning activities, namely oral exams, written guidance prompts for homework which asks students to justify their problem-solving process, and video assignment in which students perform group-explanation on homework assignments. Oral exams, due to their adaptive diagnostic nature, provide an opportunity to probe students' thought process behind their decision-making. In contrast, written exams are limited in this capacity: when students write down an equation, it is difficult to tell whether they understand the concept well or if they are trying to recall similar procedures from class examples and homework assignments. Oral exams also allow students to receive feedback from a content expert who can clear up misconceptions. Group explanation activities offer the benefits of feedback exchange and social learning among students. The paper will present the details of these learning activities as well as the outcomes. Mixed research methods were used to study the impact of verbal explanations of learning activities. Students' learning outcomes are mainly measured by exam performance. Students' perceptions were studied through both quantitative Likert-scale questions and free-response to open-ended questions.

1. Introduction

In the history of Science, technology, engineering, and mathematics (STEM) education, one of the foundations for evidence-based pedagogy were models that derived from information processing theory [1]-[2]. Although this theory had proposed active cognitive processes in memory consolidation (e.g., elaborative rehearsal [1], central executive [2]) along with the multiple modules of memory (e.g., sensory memory, long-term memory), its implementation in classroom settings often resulted in emphasis in passive rote memorization rather than active deep learning. Generative learning strategies, on the other hand, prime the learner to get involved in deep cognitive processes, such as organizing the material into structures and integrating it with prior knowledge, to eventually achieve meaningful learning [3]. Therefore, based on the generative learning model [3]-[4] we propose a series of active learning activities that enhances students' deep learning: explanatory activities that foster students' reasoning skills.

Viewing learning as *rote memorization* frames learning as knowledge acquisition, where students add new information to their memory storage, which may mistakenly frame learning as a passive process [4]-[5]. A focus on rote memorization may guide instructors to teach and assess their students on how well they remembered fragments of knowledge, which may lead to dissociation from the learning context [6]. In contrast, *meaningful learning,* or *deep learning,* approaches learning as a process where students intentionally seek to make sense of their experiences. A focus on meaningful learning guides instructors to integrate rote memorization as a means to a bigger goal, such as problem solving, which leads students to understand and create new knowledge [6].

On the students' end, meaningful learning facilitates deep and long-lasting learning by giving the student an active role as a constructivist of their knowledge (*constructivism*, [7]). Whereas passive rote memorization could result in short-term, shallow processing of new knowledge, meaningful learning engages students in cognitive processes that enables elaborative encoding. Research in learning and memory suggests that learners remember the material better when the information is connected to prior knowledge [8], organized into meaningful units [9]-[10], and personalized so that the materials are relevant to oneself [11]-[12]. With these active cognitive processes, students are able to better understand the gist of concepts in relation to the immediate context and are also able to abstract out the structural information that can be applied in novel, analogical contexts. This process is often referred to as analogical transfer of knowledge [13]-[14], which is often the learning outcome in many engineering courses (e.g., being able solve novel problems with abstract principles). Often instructors design exam questions that require analogical transfers, and students who are not familiar with deep learning strategies may have difficulty meeting the intention of these exam questions.

One way to promote deep learning in students is to help students practice generative learning strategies [15]-[18]. According to the cognitive theory of multimedia learning [19]-[20], deep learning is promoted by achieving three core cognitive processes. First, the student needs to understand and *select* the relevant material from the lesson (Stage 1). Second, the student needs to *organize* the selected materials into a coherent structure. This step has been known to be promoted by the teaching expectancy effect [21]-[22] where students perform better in selecting the abstract structural information when they have the intention to teach the material to someone else (Stage 2). Lastly, the student will be able to utilize this structural representation and integrate it with relevant prior knowledge, succeeding in solving novel, analogical problems (Stage 3).

Despite the benefits of generative learning strategies that enable long-lasting understanding on the student's end, in engineering courses its implementation has often been hindered by logistical challenges such as the class size, limited class hours, or the extensive time spent for class preparation. Therefore, in this paper we share our experience in implementing several learning activities (written guidance prompts for homework, video assignment, and oral exam) that promote generative learning with the goal of achieving meaningful learning: Specifically, we focused on stimulating students' reasoning skills by providing opportunities to generate explanations.

Generating explanations promote deep learning in students by stimulating two mechanisms: *metacognition* and *expectation for explanation*. *Metacognition* refers to the higher-level awareness of what one knows and does not know (metacognitive skills, [23]). For example, when reviewing the exam questions that they got wrong, students often realized where they had an incomplete or inaccurate understanding of the subject matter. To promote metacognition and deep learning, students need to reflect on the problem and their thought process and identify and correct their gap(s) in knowledge and/or misconceptions. They also need to be able to apply the key concept of the question to other contexts through selectively abstracting core knowledge. Generating explanations about their thought process when answering exam questions provides a structured way for students to develop metacognitive skills. Such ability to abstract out the core structural information from a given context has been promoted by self-explanation [14] and self-testing [24]-[25] in which students have a chance to metacognitively revisit the scope of their understanding of the materials.

Along with metacognition, the *expectation to explain* one's thoughts to someone else facilitates how the student organizes their thoughts into a logical stream (Stage 2 in deep learning). The benefits of explanation have been found in both simulations (expectancy) and real-life action of explanation (production of explanations). As in the teaching expectancy effect [21]-[22], simulating explaining a concept to someone else facilitates the generative learning process on the students' end. For example, several studies have shown that students expecting to teach performed better on measures of conceptual learning compared to those who did not expect to teach [26]-[27]. Verbally explaining a concept to someone else in real-life also promotes students' deep learning, and is often greater than just preparing to explain without real-life occurrences [27]. Studies that show that student tutors themselves benefit from learning from tutoring peers also supports this idea (tutor learning effect, [28]). The benefit of explaining or sharing one's thought process on the class materials with others have been well observed in small group discussions [29] and cooperative learning activities [30] as well. Nevertheless, it has not been clear how the generation of explanation can be fully implemented in engineering classrooms where assessments are often reduced to written exams or homework that does not have an interactive component.

Therefore, in our paper, the instructor who taught two different engineering classes demonstrate the use of four learning activities and assignments that promote explanation among students and therefore strengthen students' reasoning skills that promote metacognition with a goal toward strengthening students' reasoning skills. Altogether, In this paper we aim to address two research questions. First, we ask whether students' performance in metacognitive learning activities is correlated with students' overall performance in their class. We provide quantitative analysis by the type of learning activity incorporated in the class (video assignments, guidance prompts, oral examinations). Second, we ask whether students perceive as having benefited from participating in these metacognitive learning activities. We share preliminary and exploratory analysis on students' perceptions on how the learning activities such as its impact on deep learning and perceived advantages or disadvantages of participating in them.

2. Methods

In this study, we investigate two courses for which we designed and implemented explanatory learning activities for Mechanical and Aerospace Engineering (MAE) students: Course A (Statics and Introduction to Dynamics) and Course B (Solid Mechanics I). The two courses were taught by the same instructor. There are three types of explanatory learning activities designed and implemented among the two courses: written homework prompt, group video assignment, and oral exams with descriptions as following:

2A. Written Guidance prompts on homework

Written guidance prompt questions refer to guidance prompt text questions in addition to the traditional homework questions where students were only asked to demonstrate necessary work to get the problem solved. These guidance prompt questions aim to encourage the students to think explicitly about the decisions they make for the major problem-solving steps and generalize their knowledge for new scenarios application. Depending on the complexity, 5 to 8 guidance prompts were created for each problem in the homework. There are two parts of the guidance prompts, the pre-problem-solving guidance prompts, where students are asked to formulate problem-solving strategies; and the reflective prompts, which ask students to reflect and summarize their learning from the process of solving the problem. The pre-problem-solving guidance prompts are written in a way that if students can answer all of them correctly, they should be able to formulate the problem-solving process for the problem and other problems that need similar concepts. The prompt questions also promote the students to think about the general concepts behind a specific calculator process, and to minimize the “plug and chug" from similar examples. Students use this prompt guidance to think aloud and verbalize the problem-solving process and the concept behind it for the video assignment. An example of the homework guidance prompts from Course A is described in box 1.

2B. Group video assignments

Students could complete the homework guidance prompts independently. They are also encouraged to discuss the homework question in a group of three students, around but not limited to the guidance prompt questions. The group video assignments encourage students to learn through explaining to others and receive feedback on their thought processes. The students were asked to hold discussions in a group of 3 students. They take turns to lead discussions for at least one question in the group discussion and submit a video for extra credit. Students who do not participate in such group discussions and submit video assignments still need to answer the guiding questions as part of their written assignments. They could meet either online or in-person.

The discussion starts from one question led by the question leader, the rest of the group actively provide feedback and raise questions. Once done with one question, another student will lead the discussion for the next question until everyone in the group has the chance to lead at least one discussion. The discussions are encouraged to be centered around “guidance prompts” that were given for each problem, but not limited to it. Each written homework problem was accompanied by a set of guiding questions. These guidance questions provide the students with a checklist and hints on how to solve the problem and contain suggestions on “think-aloud” techniques for better conceptual mastery of the knowledge. Students are encouraged to answer these guidance questions aloud before they start the computational process to aid in their understanding of the reasoning behind the calculation process. Homework grading was based on both answers to the guidance prompts and problem-solving process. The students are also encouraged to thoroughly review the questions, then hold the group discussion meeting before they solve all problems in detail, so that they could validate their correct problem-solving strategy. Whenever the group gets stuck in a discussion, we encourage them to review the lecture and discussion materials for reference. If, after a thorough discussion, the group is still unable to arrive at the solution or is not sure, students are encouraged to attend office hours. A sample group discussion video was provided to the students. Students were encouraged to share screens to present the problem they were discussing and use the annotation tools as needed. The instructor found most discussion groups address the guidance prompts in their discussion.

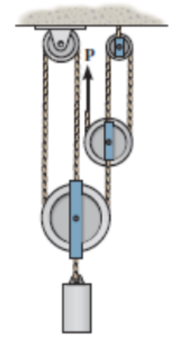
2C. Oral exams

The oral exams studied in this paper were conducted remotely over Zoom. Assessors and the testing student students were allowed to utilize the whiteboard and annotation function, and share screens to assist with presenting their answers.

The oral exam was conducted as part of the quizzes (10% of the overall course grade). Each student was asked to solve a problem during the 15-minute session with either the instructor or instructional assistant. Each student has a different version of the question, and the problem complexity was calibrated. In the oral assessment, students were given a list of 3-5 guiding questions similar to the homework assignment. Students walked through their problem-solving process by addressing the think-aloud prompts and explaining the reasoning behind each decision. If students get stuck, hints were provided to help students to move to the next step. This will allow the students to demonstrate a full picture of their knowledge. Often in written exams, students were not able to move forward when getting stuck at a critical step. Feedback was given during the oral exam, and grading was based on a predetermined rubric (0-5 scale) that assesses the correctness and reasoning of their answer. A sample oral exam question Course A is demonstrated in box 2.

The details of these learning activities are elaborated in this section. The basic course logistics information for each quarter are described in Table 1. We studied the same course from 2 different quarters to investigate the consistency and trends of the impact of the explanatory learning activities on students' learning outcomes and students' perceptions towards it.

Box 1. Sample Written Guidance Prompt for CourseA Homework Question



Determine the force P required to maintain equilibrium. The block is 100 lb.

Based on the problem description and any additional information provided below, complete the following items:

1. Before solving the main problem, answer the following prompts:
    a. What is the meaning of equilibrium? What conditions need to be met?
    b. If applicable, what object(s) should we choose to analyze for equilibrium and draw free-body diagrams for? Why?
    c. How can we best describe the force at any point within a taut cable? Based on this, deduce all forces that are equal in magnitude.
    d. Consider Newton's Third Law; what does it tell us about forces experienced by bodies interacting with each other, and how is it applicable in this situation?
    e. If applicable, how many linearly independent scalar equations can be formed from each free-body diagram? Why is it so? Where does each equation come from?
    f. Create a brief outline of your approach to solving the problem, similar to the provided example in format. For each step, list all the information that is needed and all the information that will be determined, as well as the assumptions & simplifications.
2. Solve the main problem as outlined in the problem description.
3. Once you have solved the main problem, answer the following prompts:
    g. Were there any steps in your outline which needed to be adjusted? If so, which step(s)?
    h. Sanity check: does your solution make sense? Try to justify it without explicitly using any equations.
    i. For any given mass M of the block, what would be the required P to maintain equilibrium?

Box 2. Course A sample oral exam sample question (figure credits for [31])

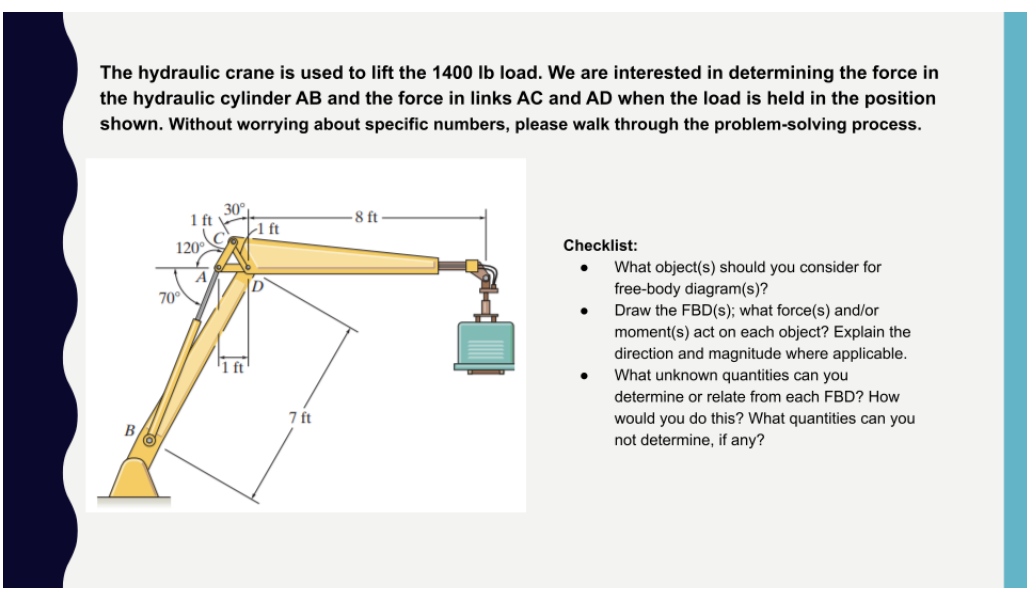


Table 1. Courses and the implemented learning activities that promote explanations in this study

Course Name	Number of students	Guidance homework prompt	Group video assignment	Oral exam	Assessment by chronological order within the quarter
CourseA -Winter 2022	n=111	Mandatory for all students	Optional, for extra credits	All students took 2 oral quizzes	2 oral quizzes, 1 midterm exam, 1 final exam
CourseA -Summer 2022	n=25	Mandatory for all students	Optional, for extra credits	No oral exams	1 midterm exam, 1 final exam
CourseB -Spring 2022	n=99	Mandatory for all students	Optional, for extra credits	For quiz1, 50% took oral quiz and 50% took written quiz; quiz 2 were flipped	1 oral quiz, 1 written quiz, 1 midterm exam, 1 final exam
CourseB -Summer 2022	n=16	Mandatory for all students	Optional, for extra credits	No oral exams	1 midterm exam, 1 final exam

3. Analysis and Results

In this study, we collected and analyzed data for the two classes from four different cohorts, to understand the correlation of the explanatory learning activity and students' learning outcomes, as well as students' perceptions of these learning activities. The details are presetend in the following section.

3.1. Learning outcome: correlation analysis between students guidance prompt completion/ score and their exam score by linear regression

3.1.A. Correlation between Homework Guidance Prompt performance and exam performance

In Winter 2022 course A, grades for guidance prompt were mainly assigned based on completion due to the large class size and limited TA resources. For summer 2022 both Course A and B, the class size were significantly smaller, thus homework guidance prompts were graded based on performance. Therefore, the correlation between guidance prompt response quality and exam performance was investigated.

As seen in Table 2, there was a very weak positive relationship between higher quality on the guidance prompt response and exam performance, with a slightly higher correlation in the final exam dataset. For summer 2022 Course A, the R^2 value between homework prompt grades &

midterm exam grade, homework prompt grades & final exam grade were R^2=0.0036 and R^2=0.0653 respectively.

When outliers were removed from the two data sets, the homework prompt and midterm correlation remained weak. The R squared value increased from 0.0036 to 0.0146. However, the correlation has strengthened significantly in the Final exam performance. The R squared value of the final exam data has increased from 0.0653 to 0.1919.

Table 2. Course A, winter 2022, correlation between homework guidance prompt score and midterm/ final exams scores (n=111)

	Midterm exam score	Final exam score	Midterm exam score (outliers removed)	Final exam score (outliers removed)
Homewrok Guidance Promot score	0.0036	0.0653	0.0146	0.1919

For summer 2022 Course B, as seen in Table 3, a moderate positive correlation was observed for both the midterm and final exam performance when compared when guidance prompt quality: homework prompt grade & midterm exam and homework prompt grade & final exam grade has a R^2 value of 0.1473 and 0.1506 respectively. It is observed that variations in guidance prompt performance increase as exam performance decreases, with several outliers present.

When the outliers are removed from the dataset, the correlation between guidance prompt and exam performance decreases significantly in the midterm data set. However, the correlation was strengthened in the final exam data set (R^2=0.3854 between homework guidance prompt response quality & final exam score).

Table 3. Course B, summer 2022, correlation between homework guidance prompt score and midterm/ final exams scores (n=16)

	Midterm exam score	Final exam score	Final exam score (outliers removed)
Homewrok Guidance Promot score	0.1473	0.1506	0.3854

3.1.B. Correlation between video assignment submission and exam performance

The correlations between video assignment submission and course assessment performance were investigated for Winter 2022 Course A, Spring 2022 Course B, Summer 2022 Course A and Summer 2022 course B. Due to the limited number of teaching assistants in these high enrollment courses, the video assignments were mainly graded based on completion with spot checks. In the future, detailed grading for these assignments may prove to be useful to gain a better understanding of the benefits of video assignments when students complete them at various levels of performance.

For winter 2022 Course A analysis, students were separated into bins based on the number of video assignments submitted prior to each assessment. A linear fit was performed, and the R^2 values were determined for the data sets. By oral exam 1 (week 3), there were 2 video assignments assigned. As seen in Table 4, a very weak positive correlation (R^2=0.0023) presented between the number of video assignments completed and oral exam 1 score. By the midterm in week 6, there were 5 video assignments assigned. A slightly stronger (still weak on the absolute scale) positive correlation (R^2=0.034) was found between the number of video assignment submissions and the midterm exam score. By oral exam 2 (in week 8), a total of 7 video assignments had been assigned. A weak positive correlation (R^2=0.017) was found between the number of video assignment completion and oral exam 2 scores. By the final exam (week 11), there were a total of 8 video assignments assigned. A weak positive correlation (R^2=0.071) was found between the number of video assignment completion and final exam scores.

Due to the large performance spread of students with zero video submissions, a second linear fit analysis was performed with only the video-submitted group. The data suggest that completion of additional video assignments in the course positively correlates with assessment (oral and written exams) performance. Particularly later in the course, when the second oral assessment and the final exam were administered, the groups of students who had completed a significant portion of the video assignments (out of the total of 8) performed better on the assessments on average.

A weak correlation was observed in the relationship between the oral exams versus the number of videos completed regardless of the zero-submission group. The R^2 value remains low for both the oral exams and the midterm. However, a moderate correlation between the final exam and the number of videos completed dataset can be seen. With the zero video submission excluded dataset of the final exam versus the number of video submissions, an R^2 value of 14% was found.

Table 4. Course A, winter 2022, correlation between video assignment completion and midterm/ final exams scores (n=111)

Number of video assignments completed	Oral Exam 1 score (week 3)	Midterm exam score (week 6)	Oral Exam 2 score (week 8)	Final exam score	Final exam score with zero video submission group eliminated
2	0.0023				
5		0.034			
7			0.017		
8				0.071	0.14

Similar investigation was done for Summer 2022 Course A. The summer course was short (weeks), thus there were 5 video assignment, one midterm exam and one final exam. As seen in Table 5, the video assignment completion was observed to have a very small positive correlation with higher exam performance if student data with zero video submissions were included. By midterm exam (week 3), students had the opportunity to complete 2 video assignments. There was a very weak correlation (R^2=0.0018) between number of video assignment completions and midterm scores. By final exam (week 11), the students had a chance to complete 5 video assignments. A weak correlation (R^2=0.0018) was found between the number of video assignment completions and the final exam score.

However, only a small portion of the class has submitted video assignments, and when zero submission data points are excluded from the analysis, exam performance correlation becomes more apparent: correlation between the number of video assignment completions and midterm exam scores has a R^2 value of 0.3349, and correlation between the number of video assignment completions and final exam scores has a R^2 value of 0.3273.

For summer 2022 Course A, The average midterm score of students that completed any video assignments was 80.86% with a standard deviation of 19.08%, while students who did not participate in the video assignment scored an average of 84.54% with a standard deviation of 12.00%. In the final exam, the average was 67.52% with a standard deviation of 23.20% for students who completed any amount of video assignments, and the average was 65.91% with a standard deviation of 12.68% for students that did not. However, due to the small sample size, no conclusion can be drawn regarding the effectiveness of video assignment completion and exam performance.

Table 5. Course A, Summer 2022, correlation between video assignment completion and midterm/ final exams scores (n=25)

Number of video assignments completed	Midterm exam score (week 3)	Final exam score	Midterm exam score (with zero video submission group eliminated)	Final exam score (with zero video submission group eliminated)
2	0.0018		0.3349	
5		0.0018		0.3273

For Spring 2022 Course B, a similar study was conducted. The assessments within this course were quiz 1 (oral assessment for 50% of the students and written assessment for the rest of students), midterm exam (written), quiz 2 (oral or written assessment for the opposite group of students from quiz 1), and the final exam (written). For the quizzes, students were divided into two equal groups, with one group taking an oral quiz and the other group taking a written quiz; the groups switched quiz format between quiz 1 and quiz 2.

As seen in Table 6, generally, there is a very weak positive correlation between the number of video assignment completion and all assessment performance. By quiz 1, there was a total of 2 video assignments assigned. There is a very weak positive correlation between the number of video assignment completions & oral quiz 1 scores(R^2=0.001) and video assignment & written quiz 2 scores (R^2=0.0021). By the time of midterm exam, when students were given 5 video assignment opportunities, the correlation between the number of video assignment completions and midterm exam is increased to R^2=0.0547. By the 2nd quiz, when students were given 7 video assignment opportunities, the correlation of video assignment completions & oral quiz 2 (R^2=0.0246) remain similar level to midterm exam, and slightly higher for the correlation between number of video completion & written quiz 2 (R^2=0.1017). Finally, by the final exam, where the students had 9 video assignment opportunities, the number of video assignment completion and final exam score present a weekly positive correlation of R^2=0.0791.

The average midterm score of students that completed any video assignments was 67.00% with a standard deviation of 2.68%, while students that did not participate in the video assignment scored an average of 62.27% with a standard deviation of 22.32%. In the final exam, the average was 60.20% with a standard deviation of 15.84% for students that have completed any amount of video assignments, and the average was 60.36% with a standard deviation of 15.45% for students that have not.

Table 6. Course B, Spring 2022, correlation between video assignment completion and midterm/ final exams scores (n=99)

Number of video assignments completed	Oral Quiz 1 score (week 3)	Written Quiz 1 score (week 3)	Midterm exam score (week 6)	Oral Quiz 2 score (week 8)	Written Quiz 2 score (week 8)	Final exam score (week 11)
2	0.001	0.0021				
5			0.0547			
7				0.0246	0.1017	
9						0.0791

3.1.C. Correlation between Oral assessment and Written Assessment performance

In Winter 2022 Course A, a moderate correlation between oral exam performance and final exam score was also observed. The oral and final exams are mandatory components of the class, and zero submission exclusion was not needed to be performed. A R^2 value of 0.3212 was observed, suggesting active recall performance of the oral exams as a good indicator for the final learning outcome.

3.2 Student's perception towards the explanation-based learning activities

Positive students' perception is a necessary condition for them to effectively engaged in the learning activities. Thus, students' feedback on the a variety of explanatory learning activities (writtten homework guidance prompt, video discussion assignment, oral exams) were collected and analyzed. The feedback was collected through web-based surveys. Data were collected and de-identified by research assistants who are not associated with the course instruction. Response rate were 71.2% for winter 2022 Course A, 56.6% for spring 2022 course B, 72% for summer 2022 course A, and 81.2% for summer 2022 Course B.

3.2.A. What is students' perception towards the homework guidance prompt?

For the two classes taught in summer 2022, students were asked about their perception about the homework guidance prompt questions.

There were 83.3% of the responded CourseA students agreed or strongly agreed, 11.1% neutral and 5.6% disagreed that ***"the guidance prompts are helpful to better understand and improve problem-solving skills"***. For Course B, the response for the same question in the same order are 92.3% agree or strongly agree, 7.7% disagreed.

More insights are obtained from the open-ended questions' responses. Students' perception of the guidance prompts are very similar: Students reported that video assignments helped with their problem solving skills and gaining new perspectives. They also mentioned some drawbacks of the video assignments:such as the time commitment needed to complete them, or some of the homework guidance prompts at times are confusing.

3.1.B. What is the students' perception on video assignments?

Students' perceptions towards the video assignment were very positive. There were 75.6% of students in CourseA winter 2022 and 69.4% in CourseB spring 2022 who did the video assignments and responded survey agreed and strongly agreed that "***the video assignments helped them to gain a deeper understanding of the course materials"*** . In winter 2022 course A. there were 22,2% reported "neutral", and 2.8% disagreed the video assignments were helpful. In spring 2022 course B, there were 25% of neutral response, and 5.6% students disagree.

From the thematic analysis of students' open-ended responses to the prompt "***what are the advantages and disadvantages/ challenges to doing the video assignments***?", more details are studied to understand why students believe the video assignments are helpful or not helpful for their learning. Students appreciate the video assignments due to the fact that they promote idea exchanges, give them new perceptions and clarifications, improve their learning productivity, and create network with their peers. The drawback that students perceive on video assignments are mainly stemming from the logistical aspects of the group study activities, such as difficulty to schedule the weekly learning session with the rest of the group out of their busy schedules, occasional team member conflicts, and the additional group study activity requires time commitment.

3.1.C. What is students' perception on Oral Exams?

We also looked into students' insight about oral exams on their learning. Students have reported very positively regarding how oral exams contribute to their understanding of the subject matter and steering their learning strategies. In Course A winter 2022, 76% of the students who took the survey agreed or strongly agreed that ***"the oral exam increased their understanding of the subject matter"*****,** 19% responded neutral, and 5% disagreed or strongly disagreed. For spring 2022, the percentage for this question in the same order are 79.5%, 14.3%, 5% and 2.2%.

For winter 2022 course A, 44.3% of the students agreed or strongly agreed that ***"the oral exams change their learning strategy"***, 30% neutral, 21.5% disagreed, and 3.8% strongly disagreed. For spring 2022, the percentage for this question in the same order are 23%, 41.1%, 30.4% and 5.5%.

There were 73.4% of the Winter 2022 course A students and 78.6% spring 2022 course B students wish their future engineering classes use oral exams. Coding analysis provides us insight into potential reasons that oral exams increase students' understanding of the subject matter. Some students reported that due to the way they prepared for the oral exam, their strengths and weaknesses were exposed and it helped highlight what they should focus on in their studying. In addition, was also revealed to students while taking the exam when the assessor prompted them with a question or scenario they had been presented with before. Students find in preparing for their oral exams they spend more time focusing on their thought process or explanation skills than they would on a written exam in which they would focus on practice problems. Some students also report practicing their explanation aloud to ensure they could explain it. In addition, students highlighted focusing on the concepts to be an important part of studying for oral exams rather than for the written exams it was more equation based.

4. Conclusion and Discussion

In this paper, we discussed our study of the implementation of three type explanatory learning activities and assessment methods (homework guidance prompts, group video assignments and oral exams) for 2 courses to enhance students' deep learning through explanations:. We have also explored students' perceived benefits and potential drawbacks of these learning activities and assessment methods. There was almost no correlation between explanatory learning activities with learning outcomes in the early assessments, and a weak correlation with learning outcomes in the end-of-quarter assessment. The correlation difference between the early assessment and later assessment outcome may be due to the fact that impact of the explanatory learning activities needs some time to build up on students. Overall, students perceived the new learning activities very positively. In the cognitive aspect, students acknowledged that the explanatory learning activities encouraged them to think about the deeper structure of the homework problem, to do more planning before solving the problem rather than rushing, to review lecture materials/ textbook rather than just rush to complete the homework. These learning behvaiors changes are characteristic of deeper learning.

There is a limitation in this study, which should be explored in future studies: Our courses had multiple active learning activities in each of them, and it would have been hard to know which activity contributed the most to the overall performance of the student in class. Future studies may address this by designing several cohorts to have one learning activity each (or, at the student's choice of one activity) so that the direct effect of learning activities on overall course performance can be better measured and compared.

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References

[1] Atkinson, Richard C., and Richard M. Shiffrin. "Human memory: A proposed system and its control processes." In Psychology of learning and motivation, vol. 2, pp. 89-195. Academic press, 1968.
[2] Baddeley, Alan D., and Hitch, Graham, J. "Working memory." in The Psychology of Learning and Motivation: 47-89, New York: Academic Press, 1974.
[3] Wittrock, Merlin C. "Generative processes of comprehension." Educational psychologist 24, no. 4 (1989): 345-376.
[4] Wittrock, Merlin C. "Generative learning processes of the brain." Educational Psychologist 27, no. 4 (1992): 531-541.
[5] Mayer, Richard E. "Multimedia aids to problem-solving transfer." International Journal of Educational Research 31, no. 7 (1999): 611-623.
[6] Mayer, Richard E. "Rote versus meaningful learning." Theory into practice 41, no. 4 (2002): 226-232.
[7] Mascolo, Michael F., Kurt W. Fischer, and K. W. Fischer. "Constructivist theories." Cambridge encyclopedia of child development (2005): 49-63.
[8] Craik, Fergus IM, and Michael J. Watkins. "The role of rehearsal in short-term memory." Journal of verbal learning and verbal behavior 12, no. 6 (1973): 599-607.
[9] Mandler, George. "Organization and memory." In Psychology of learning and motivation, vol. 1, pp. 327-372. Academic Press, 1967.
[10] Einstein, Gilles O., and R. Reed Hunt. "Levels of processing and organization: Additive effects of individual-item and relational processing." Journal of experimental Psychology: Human learning and Memory 6, no. 5 (1980): 588.
[11] Klein, Stanley B., and John F. Kihlstrom. "Elaboration, organization, and the self-reference effect in memory." Journal of Experimental Psychology: General 115, no. 1 (1986): 26.
[12] Rogers, Timothy B., Nicholas A. Kuiper, and William S. Kirker. "Self-reference and the encoding of personal information." Journal of personality and social psychology 35, no. 9 (1977): 677.
[13] Brown, Ann L., and Mary Jo Kane. "Preschool children can learn to transfer: Learning to learn and learning from example." Cognitive psychology 20, no. 4 (1988): 493-523.
[14] Chi, Michelene TH, Nicholas De Leeuw, Mei-Hung Chiu, and Christian LaVancher. "Eliciting self-explanations improves understanding." Cognitive science 18, no. 3 (1994): 439-477.
[15] Mayer, Richard E. "Applying the science of learning: evidence-based principles for the design of multimedia instruction." American psychologist 63, no. 8 (2008): 760.
[16] Mayer, Richard E., and Merlin C. Wittrock. "Problem-solving transfer." Handbook of educational psychology (1996): 47-62.
[17] Mayer, R. E., and M. C. Wittrock. "Problem solving and transfer of knowledge." Handbook of educational psychology. New York: Macmillan.
[18] Wittrock, Merlin C. "Learning as a generative process." Educational psychologist 11, no. 2 (1974): 87-95.
[19] Mayer, Richard, and Richard E. Mayer, eds. The Cambridge handbook of multimedia learning. Cambridge university press, 2005.
[20] Mayer, Richard E. "Multimedia learning." In Psychology of learning and motivation, vol. 41, pp. 85-139. Academic Press, 2002.

[21] Annis, Linda F. "The processes and effects of peer tutoring." Human Learning: Journal of Practical Research & Applications (1983).
[22] Bargh, John A., and Yaacov Schul. "On the cognitive benefits of teaching." Journal of Educational Psychology 72, no. 5 (1980): 593.
[23] Mayer, Richard E. "Cognitive, metacognitive, and motivational aspects of problem solving." Instructional science 26, no. 1-2 (1998): 49-63.
[24] Dunlosky, John, Katherine A. Rawson, Elizabeth J. Marsh, Mitchell J. Nathan, and Daniel T. Willingham. "Improving students' learning with effective learning techniques: Promising directions from cognitive and educational psychology." Psychological Science in the Public interest 14, no. 1 (2013): 4-58.
[25] Roediger III, Henry L., and Jeffrey D. Karpicke. "Test-enhanced learning: Taking memory tests improves long-term retention." Psychological science 17, no. 3 (2006): 249-255.
[26] Benware, Carl A., and Edward L. Deci. "Quality of learning with an active versus passive motivational set." American educational research journal 21, no. 4 (1984): 755-765.
[27] Fiorella, Logan, and Richard E. Mayer. "The relative benefits of learning by teaching and teaching expectancy." Contemporary Educational Psychology 38, no. 4 (2013): 281-288.
[28] Roscoe, Rod D., and Michelene TH Chi. "Understanding tutor learning: Knowledge-building and knowledge-telling in peer tutors' explanations and questions." Review of educational research 77, no. 4 (2007): 534-574.
[29] Webb, Noreen M. "Peer interaction and learning in cooperative small groups." Journal of educational psychology 74, no. 5 (1982): 642.
[30] Slavin, Robert E. "When does cooperative learning increase student achievement?." Psychological bulletin 94, no. 3 (1983): 429.
[31] Hibbeler, R. C. *Statics*. Pearson, 2016.