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Effect of a Concept Review Intervention on the Student's Knowledge Retention and Demonstration of Pre-requisite Fundamental Concepts

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Abstract

Students achieve functional knowledge retention through active, spaced repetition of concepts through homework, quizzes, and lectures. True knowledge retention is best achieved through proper comprehension of the concept. In the engineering curriculum, courses are sequenced into prerequisite chains of three to five courses per subfield — a design aimed at developing and reinforcing core concepts over time. Knowledge retention of these prerequisite concepts is important for the next course. In this project, concept review quizzes were used to identify the gaps and deficiencies in students' prerequisite knowledge and measure improvement after a concept review intervention. Two quizzes (pre-intervention and post-intervention) drew inspiration from the standard concept inventories for fundamental concepts and include concepts such as Free Body Diagrams, Contact and Reaction Forces, Equilibrium Equations, and Calculation of the Moment. Concept inventories are typically multiple-choice, in this evaluation the concept questions were open-ended. A clear rubric was created to identify the missing prerequisite concepts in the students' knowledge.

These quizzes were deployed in Mechanics of Materials, a second-level course in the engineering mechanics curriculum (the second in a sequence of four courses: Statics, Mechanics of Materials, Mechanical Design, and Kinematic Design). The pre-quiz was administered (unannounced) at the beginning of the class. The class then actively participated in a 30-minute concept review. A different post-quiz was administered in the same class period after the review. Quizzes were graded with a rubric to measure the effect of the concept review intervention on the students' knowledge demonstration and calculations. The study evaluated four major concepts: free body diagrams, boundary reaction forces (fixed, pin, and contact), equilibrium, and moment calculation. Students showed improvements of up to 39% in the case of drawing a free body diagram with fixed boundary condition, but continued to struggle with free body diagram involving contact forces.

This study was performed at a large public institution in a class size of 240 students. A total of 224 students consented to the use of their data for this study (and attended class on the day of the intervention).

The pre-quiz is used to determine the gaps (or deficiencies) in conceptual understanding among students. The post-quiz measures the response to the review and is used to determine which concept deficiencies were significantly improved by the review, and which concept deficiencies were not significantly improved by the concept review.

This study presents a concept quiz and associated rubric for measuring student improvement

resulting from an in-class intervention (concept review). It quantifies a significant improvement in the students' retrieval of their prerequisite knowledge after a concept review session. This approach, therefore, has utility for improving knowledge retention in programs with a similar, sequenced course design.

Introduction

Students achieve functional knowledge retention through active spaced repetition of concepts through homework, quizzes, projects, discussions, and lectures. However, true knowledge retention is not possible without proper comprehension of the concepts [1, 2] and will diminish over time without proper revision and review [3]. To ensure concept retention, a typical engineering curriculum is divided into multiple sequences of courses. Each sequence covers a subfield and reinforces core concepts over several semesters. The structural mechanics' curriculum in mechanical engineering is a sequence of four courses: Statics, Mechanics of Materials, Mechanical Design, and Kinematic Design. Each course is focused on core concepts that are prerequisites to the following course, in order for students to develop a deep knowledge through the sequence. Assessing student comprehension levels and identifying gaps in students' knowledge can help educators plan and organize their course by adding timely review and/or remedial sessions. Adding a timely and relevant remedial review is particularly important for educators during and after the COVID-19 pandemic, since prerequisite learning objectives may have suffered from the shift to online teaching. Educators have implemented multiple teaching techniques such as increasing peer-to-peer instruction, introducing hands-on experiments, implementing flipped classrooms, as well as regular short assessments in Statics [4, 5, 6] and Mechanics of Materials courses [7] to assess and improve the students' knowledge and skills.

Concept inventories are an established way to assess student knowledge [8, 9, 3] that can quickly and reliably identify any gaps in their knowledge. An intervention framed by pre- and post-intervention concept inventory quizzes, referred to as pre-quiz and post-quiz in this paper, can measure gaps in prerequisite knowledge. The knowledge gaps identified through the second concept inventory can indicate the concepts that require a more targeted remedial session. The idea of pre- and post-assessments has multiple precedents in analyzing various teaching techniques [4, 7, 10]. The long-term objective of this research is to implement interventions at multiple stages during the engineering mechanics curriculum. The goal of these implementations will be to identify knowledge retention/decay in fundamental concepts and to assess the effectiveness of a quick review session.

In this manuscript, the intervention is tested in the Mechanics of Materials course to measure its effectiveness. The manuscript discusses the procedure to implement the intervention (quizzes and review session), measurement rubric for the quizzes, and assessment of quizzes to measure the knowledge gaps and improvements.

Methods and Procedure

The concept review intervention was implemented in a sophomore-level course called Mechanics of Materials – second in a four-course sequence of engineering mechanics. The prerequisite course, Statics, covers fundamental concepts of mechanics like free body diagrams(FBDs), boundary reaction forces (fixed, pin, and contact), equilibrium, and moment calculation. The concept review quiz created for this study was motivated by the Dynamics Concept Inventory [11, 9, 12]. For this study the questions are open ended rather than multiple choice like the Dynamics Concept Inventory to avoid concerns about guessing and obtain a better measure of student understanding [13].

The objective of this intervention is to identify gaps in students' prerequisite knowledge, to fill the gaps through an active learning session, and to measure the improvement and effectiveness through concept inventory quizzes. This 50-minute intervention was conducted in the third lecture of the spring 2020 semester. The procedure is presented in Table 1.

Time (0-50 minutes)	Procedure	
0-1 minutes	Divide the class into two sections (random)	
	Group 1 (113 Students)	Group 2 (121 Students)
1-11 minutes (Pre-Quiz)	Conduct Quiz A	Conduct Quiz B
11-40 minutes (Concepts review)	1) Review all the concepts in brief 2) Ask students to solve similar questions 3) Allow peer-to-peer feedback 4) Provide answers and feedback to students' questions	
40-50 minutes (Post-Quiz)	Conduct Quiz B	Conduct Quiz A

Table 1: Intervention Implementation Procedure During a 50-minute lecture.

At the beginning of the class, an unannounced pre-quiz was conducted to identify and measure the concept gap in students' knowledge. After the pre-quiz, a concept review session was conducted to discuss and review concepts. This review session discussed the concepts on the quiz, but did not address the specific questions in the quiz. Students were asked to practice concepts in pairs and the instructor provided guidance. After this 30-minute intervention, a post-quiz was conducted to evaluate students' knowledge retrieval.

To resolve any concerns about the validity and comparison of the pre- and post-quizzes, the class of 240 students was randomly partitioned into two groups. The classroom seating was composed of a left and right column with a walkway down the center. The left side of the classroom was designated Group 1, which was comprised of 113 students. The right side of the classroom was designated Group 2 which was comprised of 121 students. Two quizzes were created. Group 1 took Quiz A as the pre-quiz and Quiz B as the post-quiz. Group 2 took Quiz-B as the pre-quiz and Quiz-A as the post-quiz. Due to the swapping of quizzes, students were not assessed with the same questions in pre- and post-quizzes but using the same concepts. Due to the group selection process, any variance in the difficulty of the quizzes could be identified.

Inventory Quizzes and Rubrics: Two separate quizzes (Quiz A and Quiz B) were prepared using a group of fundamental concepts identified by reviewing a standard concept inventory [9, 8]. The quizzes are attached in the Appendix . Each quiz has three questions exploring multiple concepts and sub-concepts (See Table 2). Questions are designed to be open-ended to thoroughly assess the students progress and improvement. A grading rubric for these concepts and subconcepts was created for assessment and is presented in Table 2.

Question1: Can students draw FBD correctly?
Can students infer the changes in FBD due to addition/subtraction of elements?

Subconcepts	Correct (1-2 points)	One Mistake (1 point)	Wrong (0 points)
FBD of A is unaffected by the addition of Block C	No change in FBD of A (1 point)		Change in FBD of A
FBD of B is affected by the addition of Block C	Added string tension in FBD of B (1 point)		Did not add string tension in FBD of B
Overall competency with drawing a point mass FBD, measured by FBD of Block A	All the forces are present with their correct directions (2 points)	One force is missing or one force direction is wrong (1 point)	Two or more forces are missing or with two or more wrong force directions.

Question2: Can students identify the boundary reactions for FBD?

Subconcepts	Correct (2 points)	One Mistake (1 point)	Wrong (0 points)
Construct reaction forces at Point A by identifying the boundary condition	Two reaction forces (a horizontal and a normal force on the surface)	One force is missing or the direction of force is wrong	Reaction forces are missing
Construct reaction forces at Point B by identifying the boundary condition	One force perpendicular to the contact surface	Force is not perpendicular to contact surface or more than one force	Contact force is missing
Overall competency with drawing a rigid body FBD	All the forces are present with their correct directions	One of the contact/reaction forces missing or Contact force direction is wrong	Two or more forces are missing or with two or more wrong force directions

Question3: Can students identify the boundary conditions for FBD?
Can students compose the equilibrium equations for forces and moments?

Subconcepts	Correct (2 points)	One Mistake (1 point)	Wrong (0 points)
Draw FBD of L shape or curve rod	All the forces are present with their correct directions.	One force is missing or One force direction is wrong.	Two or more forces are missing or incorrect.
Equilibrium equation for forces in x-direction	Correct equation	Equation with one mistake in direction of force	Missing force, or two or more wrong directions
Equilibrium equation for forces in y-direction	Correct equation	Equation with one mistake in direction of force	Missing force, or two or more wrong directions
Equilibrium equation for moment	Correct equation	Equation with one mistake in direction of moment	Missing moment, or two or more wrong directions

Table 2: Quiz Grading Rubric. Grading points are assigned for each subconcepts based on correct answers, answers with one-mistake, and wrong answers for a total of 18 possible points.

Both quizzes were developed to ask equivalent concepts and subconcepts, but have sufficient variation that students would not identify the questions as being identical.

In the first question, students are asked to draw FBD of Block A and B for two different cases. This question provides student's comprehension of drawing an FBD on adding and subtracting elements in the system. Subconcepts evaluated through this question are: the FBD of A does not change when Block C is added, FBD of B will have an added tension when C is added, and general competency with drawing an FBD (measured by the FBD of A).

In the second question, students are asked to draw FBD of Rod AB. This question identifies the students' knowledge of interpreting boundary elements at corner A and contact reaction force at wall B.

In the third question, students are asked to draw the FBD of a curved or L-shaped rod and compose equilibrium equations for the forces and moments. This question identifies the student's knowledge of interpreting boundary elements, calculating moment, and composing equilibrium equations for moment and forces in x and y directions.

Review Session: A 30-minute review session was prepared to address the concepts found in the quizzes discussed above. The review session started with a brief five-minute review on FBD using an example where a block of mass is connected with multiple strings. Then, reaction forces were discussed for various boundary elements such as fixed, pinned, hinged, roller, and simple contact elements. Students were actively involved in providing reaction forces and deflections for each of the boundary elements. Another example of a beam with multiple forces was introduced to review forces and moment equilibrium equations. Lastly, students were asked to solve a question based on similar concept. They first worked on the concepts individually and were later allowed to have peer-to-peer discussion time. Any queries and questions during this discussion time were answered by the instructor and teaching assistants.

Results and Discussion

The grading rubric (Table 2) was used to grade the students' quizzes to identify gaps in their knowledge and post-review improvement. The measured grading data is used to answer three questions:

1. What gaps or deficiencies in concepts do students have before the review?
2. What concept deficiencies were significantly improved by the concept review session?
3. What concept deficiencies were not significantly improved by the concept review session and will require a remedial intervention?

Figure 1 shows the change in student scores between the pre- and post-quizzes. The increase in students providing correct answers in the post-quiz varies from 3% to 39% depending on the subconcepts. The largest of these, a 39% improvement in Question 3, drawing the FBD of the curved beam, involves representing boundary reaction forces and moments. The second highest increase, 29%, occurred in Question 2, which asked students to identify the reaction forces at the corner (or pin). We infer from these scores that most students understood how to represent boundary reaction forces after the concept review. There was a 5% improvement in Question 2,

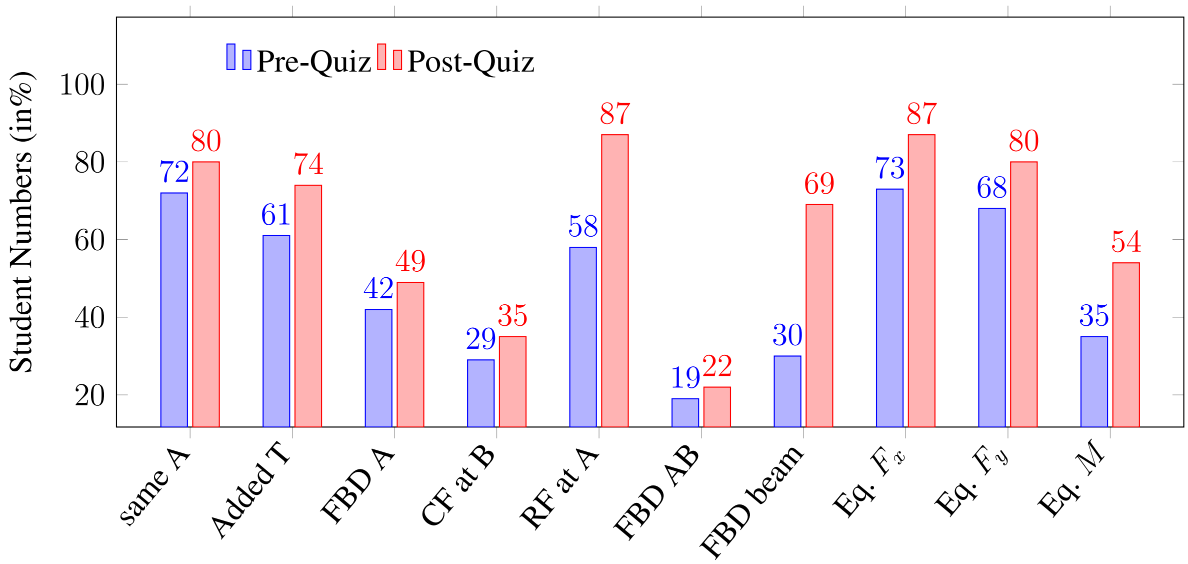

Figure 1: Concept retention improvement in number of students with correct answers after the concept review. Where acronyms are CF for contact force, RF for reaction force, and Eq. for the equilibrium equations.

identifying the correct contact force for the slope at B. This concept was tied to the rubric item "FBD of rod AB," and was the primary reason students missed this item, as seen by the 3% improvement for the FBD. From this, we infer that students did not understand the concept of normal force reactions during the review session and need a remedial session or another review session for this concept.

Another way to evaluate the data is to look at the net progression of students. To achieve this, students were graded based on how close they were to the rubric item. They were grouped into three categories: correct, one mistake, or more than one mistake (See Fig. 2). The arrows show the net flow of students moving who improved their answers, and should not be thought of as representing unique students. For example, some students went from one mistake to more. This analysis is important because it shows that even though some students were not able to get the problem completely correct after the review session, they still demonstrated improvement. A significant number of students moved out of the two or more mistakes category into the one mistake category.

Finally, each student's performance on the pre-quiz is compared with their corresponding post-quiz results. The data is sorted according to the overall quiz grades in the pre-quiz shown in Fig. 3. Students' grades are grouped together with their pre-quiz grades as shown in blue marks and corresponding post-quiz grades in red marks. The mean and standard deviation on post-quiz grades of each grade set are calculated and shown in Fig. 3.

Each quiz is set with a maximum of 18 grading points where, for first and second concepts are treated as a binary (right or wrong) and one point is provided per correct answer (see Tab. 2). The next eight subconcepts are graded on a spectrum, two points are awarded for a correct answer and one point for an almost correct answer (one mistake). Most students showed an improvement

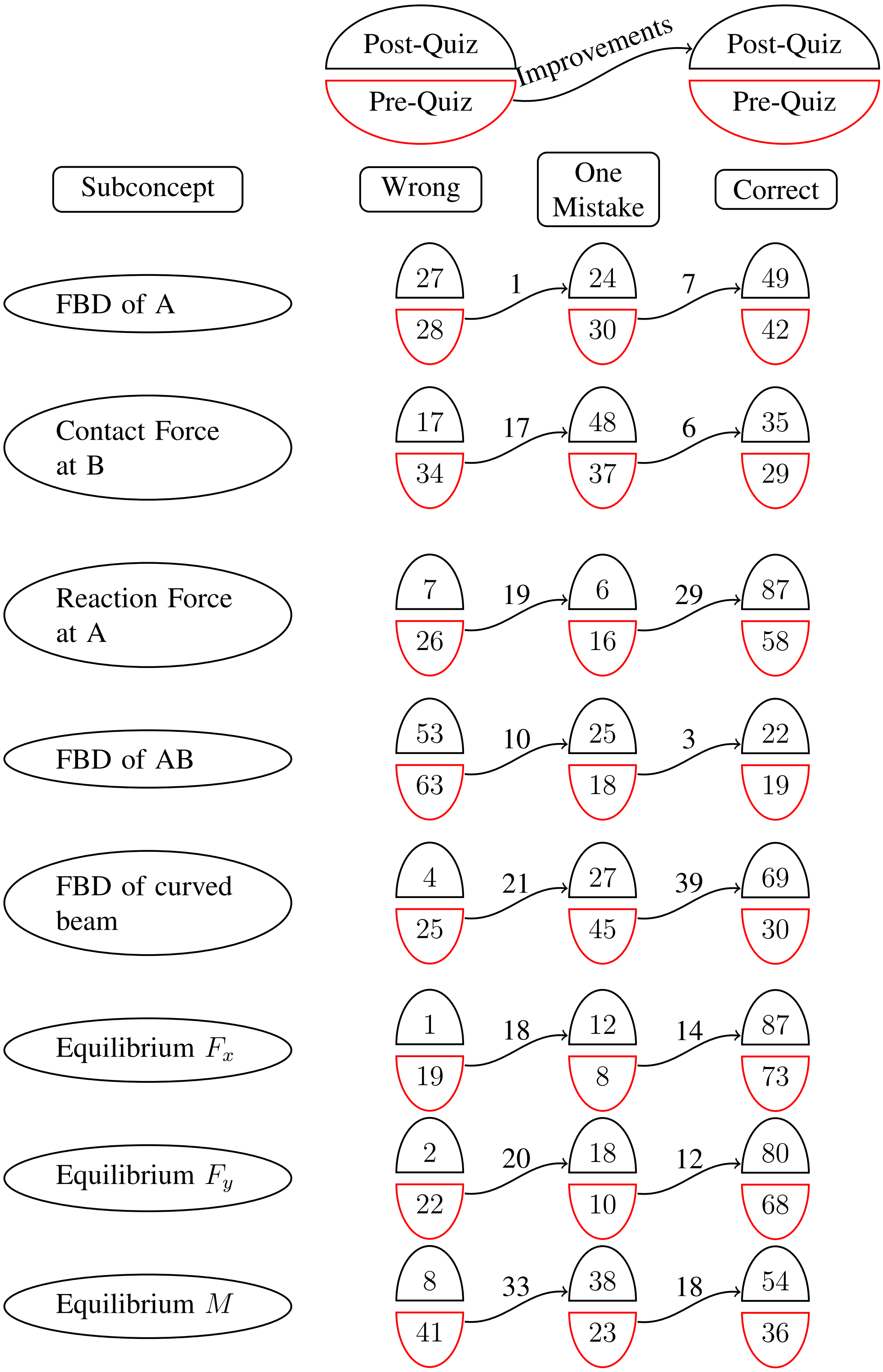

Figure 2: Arrows show the net flow of percentage students who improved their answers after the concept review intervention. For Equilibrium M, 18% of students improved to a correct answer in general and 33% of students improved from wrong answer to one mistake or correct answer.

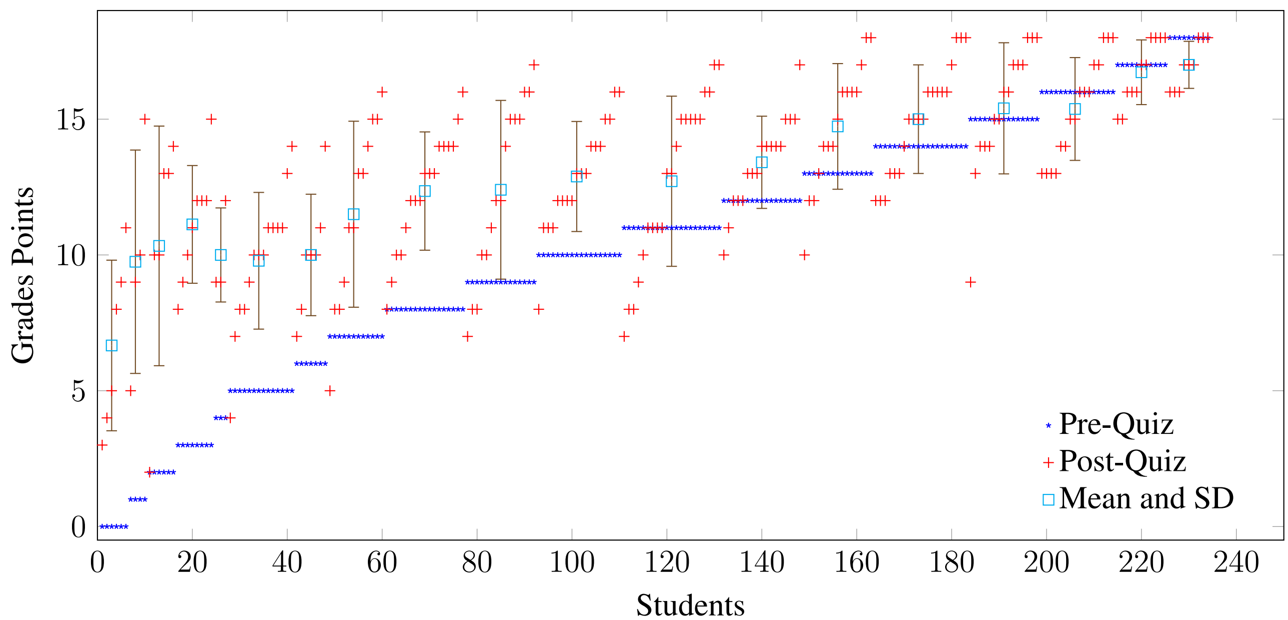

Figure 3: Pre-quiz and post-quiz grades of each student sorted by pre-quiz performance, along with mean and standard deviation of the post-quiz performance.

after the intervention, with maximum improvement in students who scored less than 11 points. Out of 234 students, 167 students (72%) improved, 22 students (9%) remained unchanged, and 45 students (19%) scored worse, with nine students scoring 2 points less than they did on pre-quiz. Students with reduced grades have a pre-quiz mean of 14.07 grade points and a post-quiz mean of 12.24, which is higher than the overall pre-quiz mean (10.42) and near to the post-quiz mean (13.08).

Both groups have several students who scored lower on the post quiz, however there are some indications that Quiz B may have been slightly more challenging than Quiz A. Of the 113 students in Group 1 who took Quiz A first, 29 scored lower on Quiz B. Of the 121 students who took Quiz B first, only 16 students scored lower on Quiz A. This result is mirrored when looking at significant student improvements. More than 67 students (30%) in the study improved significantly (more than 4 grade points). Group 2 students were more likely to have significant improvement (38/121) than Group 1 students (29/112). Because of the two Group approach, the differences in quiz difficulty do not adversely affect the results of this study.

It is worth noticing that there were no students who scored lower than one grade point in the post-quiz. Also, only 10 students scored less than 8 grade points in the post-quiz, this is an improvement from 60 students who scored below 8 points in the pre-quiz.

The pre-quiz successfully identifies core concepts in which students struggled to provide correct solutions. A 30-minute review session refreshed their core concept knowledge, as evidenced by students performing better in the post-quiz (see Fig. 2). Concepts including; FBD of curved beam, reaction forces, and equilibrium equations for forces, improved significantly. The post-quiz also identifies core concepts that did not improve, such as, drawing FBD, understanding of contact force reaction, and equilibrium equation for moment. Students would benefit from a remedial session to review or better learn these core concepts and remove misconceptions before proceeding in the course.

Conclusions and future works

This paper presents an intervention that utilizes concept quizzes and review (pre-quiz, review, post-quiz) to measure and improve the students' knowledge retention. The intervention resulted in improved quiz scores for 72% of the students. The intervention resulted in a significant improvement for more than 30% of the students. We consider an increase of 5 or more points a significant improvement. Knowledge gap identification can help instructors revise teaching methods in prerequisite courses or help instructors target material in remedial review lectures.

The authors initially planned to use similar interventions to measure students' concept retention across the two-year mechanics sequence (four courses). These measurements would help to resolve questions about short-term vs. long-term retention of knowledge. However, this part of the study was delayed by the COVID-19 pandemic. In the future, the authors would like to finish this two-year study to address the long-term concept retention of core concepts in engineering mechanics.

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IRB Approval: Authors's acquired the approval from institutional review board (IRB) Michigan State University for this intervention under the STUDY00003639. Students' identification are omitted during the grading and measuring performances to follow the IRB guidelines.

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Appendix: Quizzes used in the intervention

Quiz-A

Problem1: Use figure 1 and figure 2 to answer the follow questions. Massless cables are supporting blocks of equal weight.

a) Draw the free body diagram (FBD) for block A and block B for figure1.

b) Draw the FBD of the block A and B for the figure2.

Figure 1

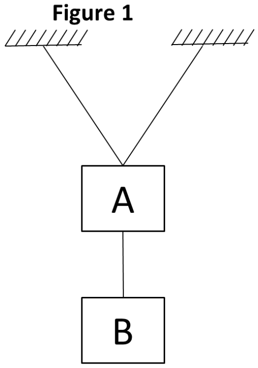
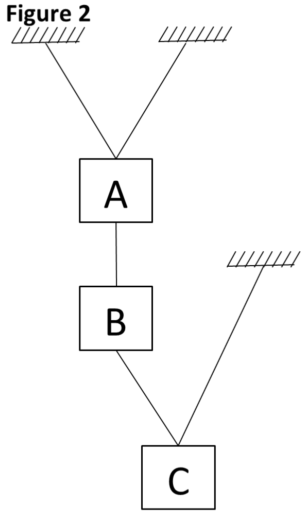
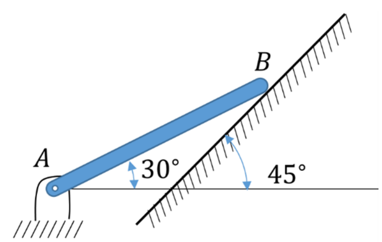


Figure 2



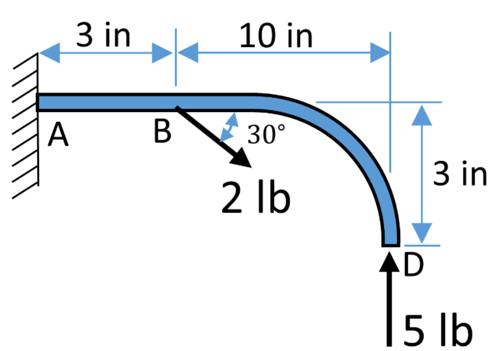
Problem2:
The rod shown is pinned at point A and point B is resting on the frictionless surface (as shown). Beam AB has a mass, m. Draw a FBD for rod AB.



Problem3: A curved beam is welded to a rigid wall at A. Two forces are applied on the beam as shown.

a) Draw the FBD of this beam.

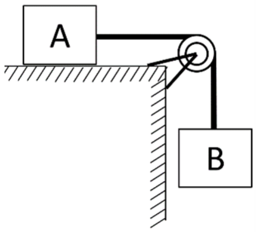
b) Calculate
the reactions (and moments) at the end of the beam.



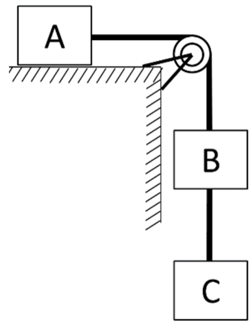
Quiz-B

Problem1: Use figure 1 and figure 2 to answer the follow questions. Block A rests on the surface and is held in place with static friction. A rope goes over the pulley and connects to block B. All three blocks have the same mass.

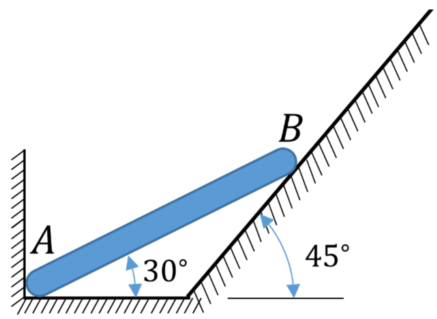
a) Draw the free body diagram (FBD) for block A and block B for figure1.



b) Draw the FBD of the block A and B for the figure2.



Problem2:
The rod shown is pinned at point A and point B is resting on the frictionless surface (as shown). It has a mass, m, Draw a FBD for rod AB.



Problem3: A curved beam is welded to a rigid wall at A. Two forces are applied on the beam as shown.

a) Draw the FBD of this beam.

b) Calculate the reactions (and moments) at the end of the beam.