

Learning Engineering Concepts through Teaching It

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Abstract

Some engineering concepts can seem trivial to students despite their struggles to fully comprehend them. This contradiction stems from the gap between the student's experiential and domain knowledge of the topic. Once the student bridges the gap, the contradiction is resolved, and the concept is learned profoundly. Considering the demonstrated benefits of expecting to teach on learning and memory, the present study aims to help students bridge the gap by asking them to teach the engineering concepts to their audience of choice (friends, classmates, family members or an imaginary student).

The process of learning engineering concepts through teaching them is studied via a Kinematics of Mechanisms course at a mid-sized technological university. The effectiveness of the method is studied through three modules: weekly group quizzes, a term project, and a midterm exam. The group quizzes provide one-on-one sessions, in which students get to work on the given problem with their partner. The term project challenges students to work on an open-ended problem of their choosing in a larger group. The midterm exam allows the students to review the topic that they struggle with by teaching it to an audience of their choice.

The three modules are explained, and the effectiveness of them is studied through tracking the students' grades and results of a self-evaluation survey designed by the instructor.

Keywords

Learning through Teaching, Group Quizzes, Engineering Communication

Introduction

Many undergraduate mechanical engineering concepts have been developed and remain unchanged for many decades. For example, the principles of solid and fluid mechanics, heat transfer, and thermodynamics were developed hundreds of years ago and continue to be central to the study of mechanical engineering [1]. This unchanging nature of many mechanical engineering concepts is what makes them so familiar to students. Nonetheless, they may still find it difficult to grasp the underlying principles and mathematical derivations that govern their behavior and hence, struggle with analyzing or designing such systems. Studies have shown that students often struggle with mechanical engineering concepts due to a lack of prior knowledge and a poor foundation in mathematics and physics [2].

Project-based learning, problem-based learning [3], inquiry-based learning [4], and experiential learning [5] are among the pedagogical methods used in engineering education that emphasize active learning, student-centered approaches, and engagement with real-world problems. One pedagogical approach that relates directly to the current study is the use of peer teaching. Peer teaching involves students teaching and learning from each other in a structured and collaborative manner. This approach has been shown to have several benefits, including

38 improved understanding of the material, increased confidence, and better retention of knowledge
39 [6] - [7].

40 Given the well-established benefits of teaching in enhancing learning and memory [8] - [10], the
41 current study seeks to bridge the gap between knowing a subject intuitively and grasping the
42 underlying principles by encouraging the students to teach engineering concepts to a third
43 person. By doing so, students will be able to apply their knowledge and skills, reinforce their
44 understanding, and gain a deeper appreciation of the material. Additionally, teaching the
45 concepts to others will challenge students to think critically about the material and clarify any
46 misunderstandings or misconceptions they may have. We hypothesize that through this process,
47 students will be able to further develop their expertise in mechanical engineering, and better
48 prepared to tackle real-world problems.

49 In particular, the current study focuses on the effectiveness of learning Kinematics of
50 Mechanisms concepts through teaching them at a mid-sized technological university. The course
51 description, the learning modules designed to test the hypothesis, and the results are provided
52 next.

53 **Course Description**

54 The main objective of the Kinematics of Mechanisms course is to learn the fundamentals of
55 planar mechanisms, their analysis and synthesis techniques. The consequent outcomes are:

- 56 • ability to analyze mechanisms/linkages using graphical and analytical techniques;
- 57 • ability to synthesize mechanisms/linkages using manual and computational techniques
58 for a user requirement;
- 59 • ability to use different computational tools related to kinematics;
- 60 • ability to solve structured and unstructured design problems; and
- 61 • improving technical communication skills through preparation of professional reports and
62 presentations.

63 Three modules are designed to study the efficacy of learning engineering concepts through
64 teaching them:

- 65 1. Weekly group quizzes
- 66 2. Midterm exam
- 67 3. Group project

68 The listed modules and the methodology of the study in each are described below.

69 **Modules**

70 *Weekly Group Quizzes*

71 The students are asked to work on a quiz problem with a teammate of their choice. The problem
72 often summarizes the concept covered throughout the week. The two teammates who are
73 naturally at different phases of learning with different understandings of the problem are asked to
74 work on the problem for 30 minutes. Since the students are asked to submit one quiz for the
75 team, they engage in an exchange of information to come up with one unified answer. The
76 authors believe this semi-private exchange between two peers results in better understanding of
77 the topic. Some students have expressed that they felt more confident asking seemingly trivial
78 questions from a classmate whom they had felt comfortable to take the quiz with. To facilitate a
79 productive discussion the instructor frequently checks the progress of the teams and provides
80 feedback. S/he then uses the remaining 20 minutes of the class time to solve and explain the
81 problem, and the quiz grade is awarded to all who participate in the discussion, regardless of the
82 correctness of their submissions. A student who participated in a similar quiz format in a
83 different mechanical engineering courses (Heat Transfer) wrote in their course evaluations that “I
84 also think the quizzes were helpful in giving me a way to do problems without being worried
85 about getting incorrect answers but focusing on the process and the concepts of solving the
86 problem”.

87 *Group Project*

88 A term group project is assigned to the students, in which they design, analyze, and fabricate a
89 simple mechanism to help a community in need. They are asked to explain and document the
90 working principles of the mechanism in simple words to the non-technical community. A low-
91 cost water filter mechanism, a can crusher, a pill puncher, a pet feeder, a corn sheller are among
92 the proposed projects. The key aspects of the project are to solve an open-ended real-world
93 problem, and to explain their designed mechanism and its functionality to the non-technical
94 target community.

95 *Midterm Exam*

96 The midterm progress of students is evaluated via a traditional exam covering 4 topics. Once the
97 exam is graded, the lowest-scoring question/topic for each student is identified. Then the student
98 is given the option to restudy the topic over a weekend, teach it to someone else (a friend, a
99 family member, or an imaginary person) and take a make-up exam on the same topic with a
100 similar question to that of the exam. They are asked to record themselves teaching and share the
101 videos for credit. The students are encouraged to use any means they deem necessary to teach the
102 subject. Using a whiteboard, sharing their tablet/computer screens, discussing the topic and
103 solving a sample problem, and having live audience are among the tools they used to teach the
104 topic.

105 **Results**

106 The effectiveness of learning modules is studied through tracking the students’ grades and results
107 of a self-evaluation survey designed by the instructor.

108 *Grades*

109 14 students (out of 29) opted to teach their lowest-scoring midterm topic and retake a make-up
110 exam. The lowest and highest scores who took the make-up exam were 12 and 68 (out of 100),

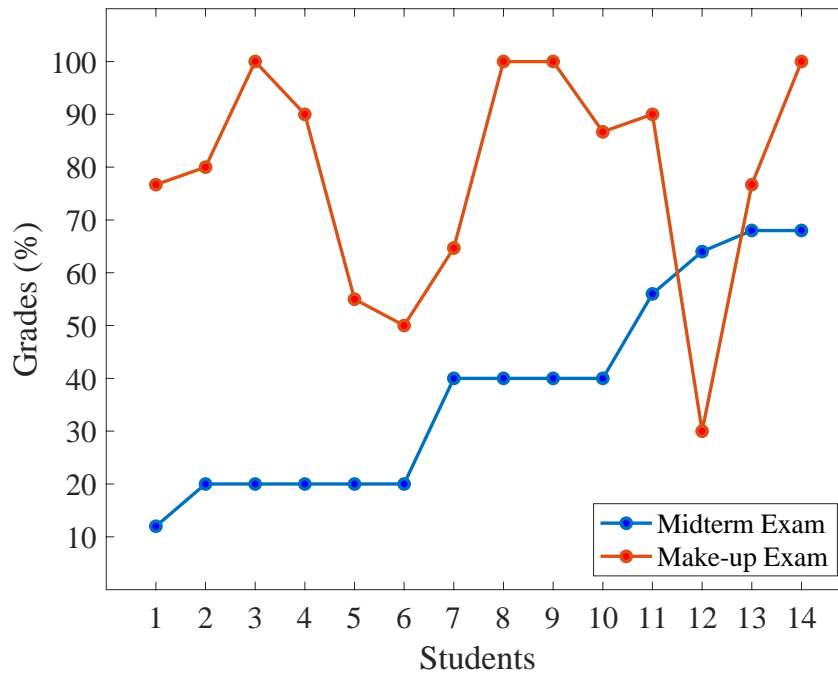


Figure 1 - Grades in the midterm and make-up exams.

111 respectively. The make-up exam problems were designed to have identical objectives and be
 112 similar in degree of difficulty to those of the midterm. The midterm and make-up exam grades
 113 are plotted in Figure 1. The average observed improvement is 40.8% with a standard deviation of
 114 29.4%. Except for one student, all other students earned significantly higher grades for their
 115 second attempts.

116 *Self-Evaluation Survey*

117 A short survey was designed and distributed by the instructor so the students would self-
 118 evaluate the impact of the modules on their learning process. The survey questions are listed as
 119 follows:

120 Q1: The weekly quizzes were helpful in better learning the topic (range of responses: A:
 121 Strongly disagree, B: Somewhat disagree, C: Neither disagree, nor agree, D: Somewhat agree, E:
 122 Strongly agree)

123 Q2: I _____ my partner during the quizzes (range of responses: A*: Mostly learned
 124 from, B*: Occasionally learned from, C*: Neither learned from nor taught to, D*: Sometimes
 125 learned from and sometimes taught to, E*: Occasionally taught to, F*: Mostly taught to)

126 Q3: Teaching the area of my weakness in the exam helped me better understand the topic (range
 127 of responses: A-E)

128 Q4: Working on an open-ended project helped me better understand the topic (range of
 129 responses: A-E)

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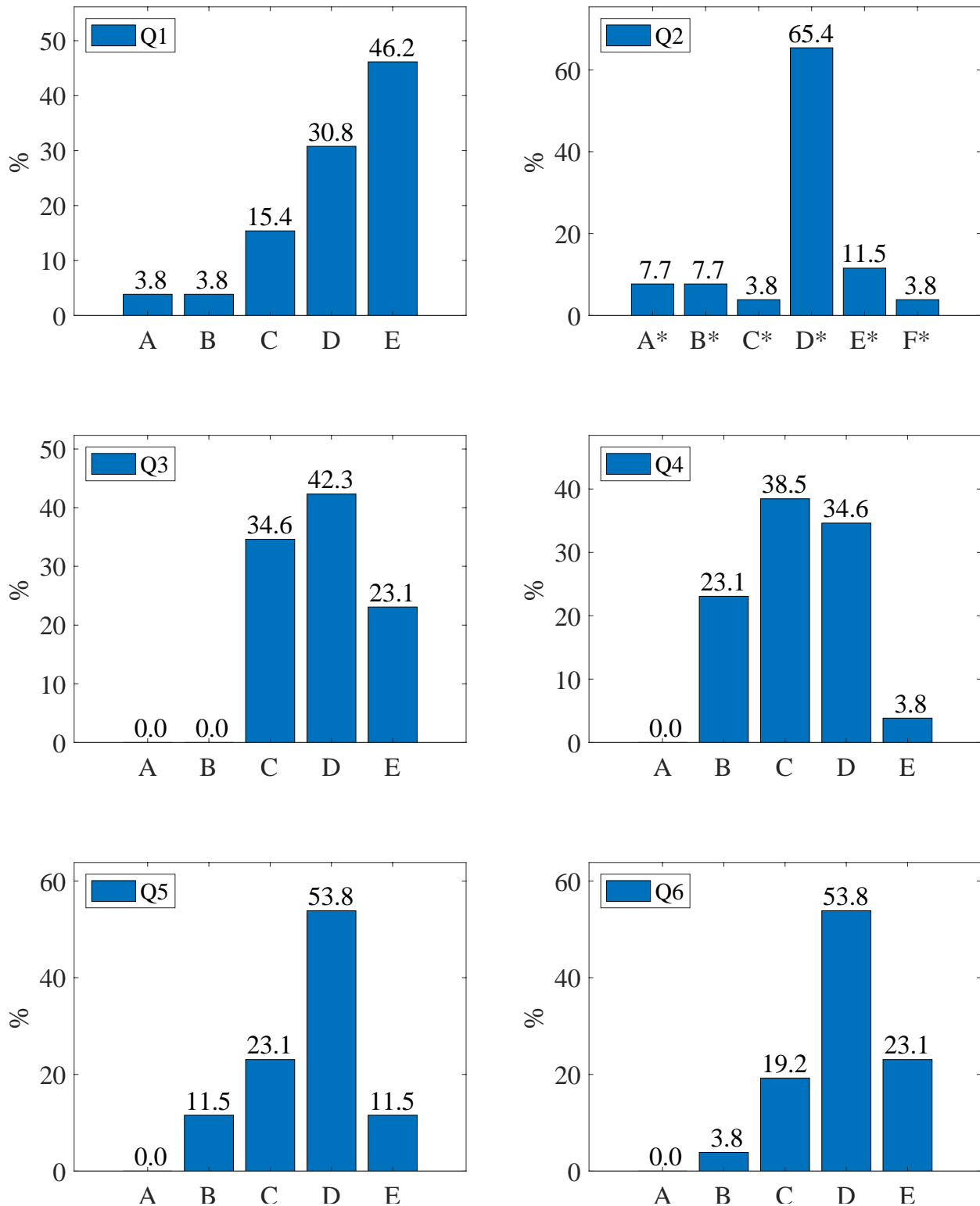


Figure 2 - Student responses to the survey questions.

130 Q5: I had a better experience in Kinematics of Mechanisms compared to similar courses (range
 131 of responses: A-E)

132 Q6: I would rather other professors implement similar learning modules in their syllabi (range of
133 responses: A-E)

134 The results of the survey are plotted in Figure 2. Twenty-six students participated in the survey
135 (90% of the class population). 77% agreed that the weekly quizzes, and 65.4% agreed that
136 teaching the area of their weakness in the exam helped them better understand the topic (Q1 and
137 Q3, respectively). The number of responders who agreed that teaching the topic for the make-up
138 exam helped them (17) is more than those who took the make-up exam (14). The instructor
139 believes some students taught the topic but did not take the exam. 38.6% agreed that working on
140 an open-ended project helped them better understand the topic (Q4). The authors conjecture that
141 the lower percentage of this module compared to the others is attributed to the timing of the
142 survey, which was conducted shortly after the midterm. Historically, the students tend to not start
143 working on the project seriously until the final weeks. The survey results show there is a
144 profound two-way discussion in the weekly quizzes as 65.4% of the students indicated they
145 sometimes taught to and sometimes learned from their partners during the weekly quizzes (Q2).
146 In summary, the students found the offered learning modules helpful in their learning process as
147 65.3% had a better experience in Kinematics of Mechanisms compared to similar courses (Q5)
148 and 76.9% would rather other professors implement similar learning modules in their syllabi
149 (Q6).

150 **Conclusions and Future Work**

151 The results of the survey and grades of the make-up exam confirm the effectiveness of the
152 learning modules implemented in the course. There are a few changes that the authors would
153 recommend for future studies. The authors believe postponing the survey towards the end of the
154 term would provide a more accurate assessment by the student. The extra time would allow them
155 to work more on the project, and provide a larger sample size on the effect of the modules on
156 their learning process. Moreover, having a control group who could take the make-up exam
157 without having them to teach the topic would better allow the authors to gauge the effectiveness
158 of the method.

159 Despite the demonstrated benefits of the implemented methods, it is important for students and
160 instructors to weigh the potential benefits and drawbacks of them before adopting them. For
161 instance, retaking an exam can be time-consuming and require additional effort and study, which
162 can be a burden on students who are already busy with other coursework, work, or personal
163 commitments. Moreover, students who teach their peers may become overconfident in their
164 understanding of the material, which can lead to complacency and errors in their own learning.

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