Learning Engineering Concepts through Teaching It

Prof. Alireza Ebadi, Worcester Polytechnic Institute
Prof. Ahmet Can Sabuncu, Worcester Polytechnic Institute

Dr. Sabuncu holds a Ph. D. in Aerospace Engineering from Old Dominion University. Dr. Sabuncu's professional interests spans from engineering education research, history of science and engineering, thermo-fluids engineering, and microfluidic technology.

Learning Engineering Concepts through Teaching It

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

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

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

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

Course Description

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

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

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

1. Weekly group quizzes
2. Midterm exam
3. Group project

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

Modules

Weekly Group Quizzes

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

Group Project

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

Midterm Exam

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

Results

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

Grades

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

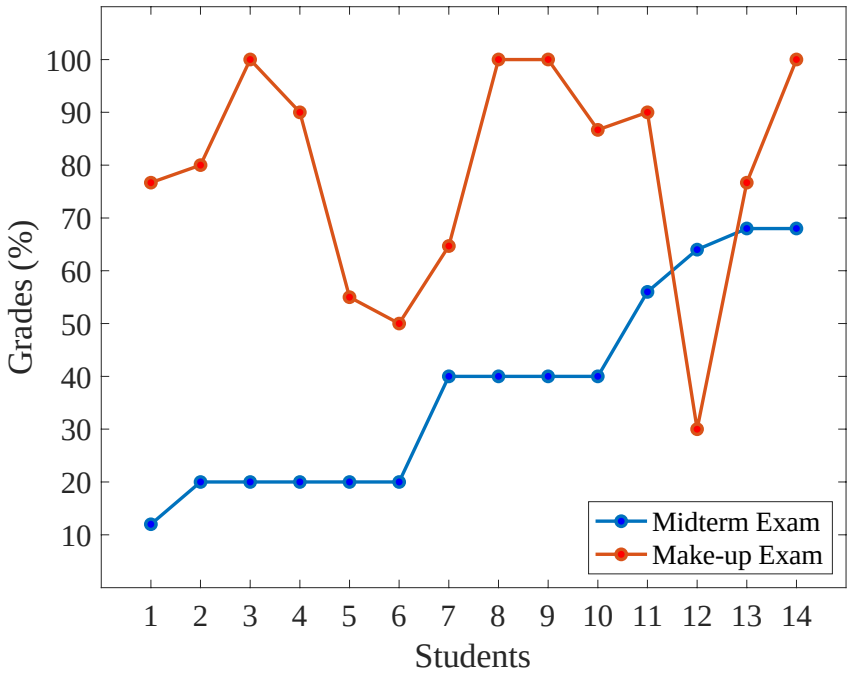

Figure 1 - Grades in the midterm and make-up exams.

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

Self-Evaluation Survey

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

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

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

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

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

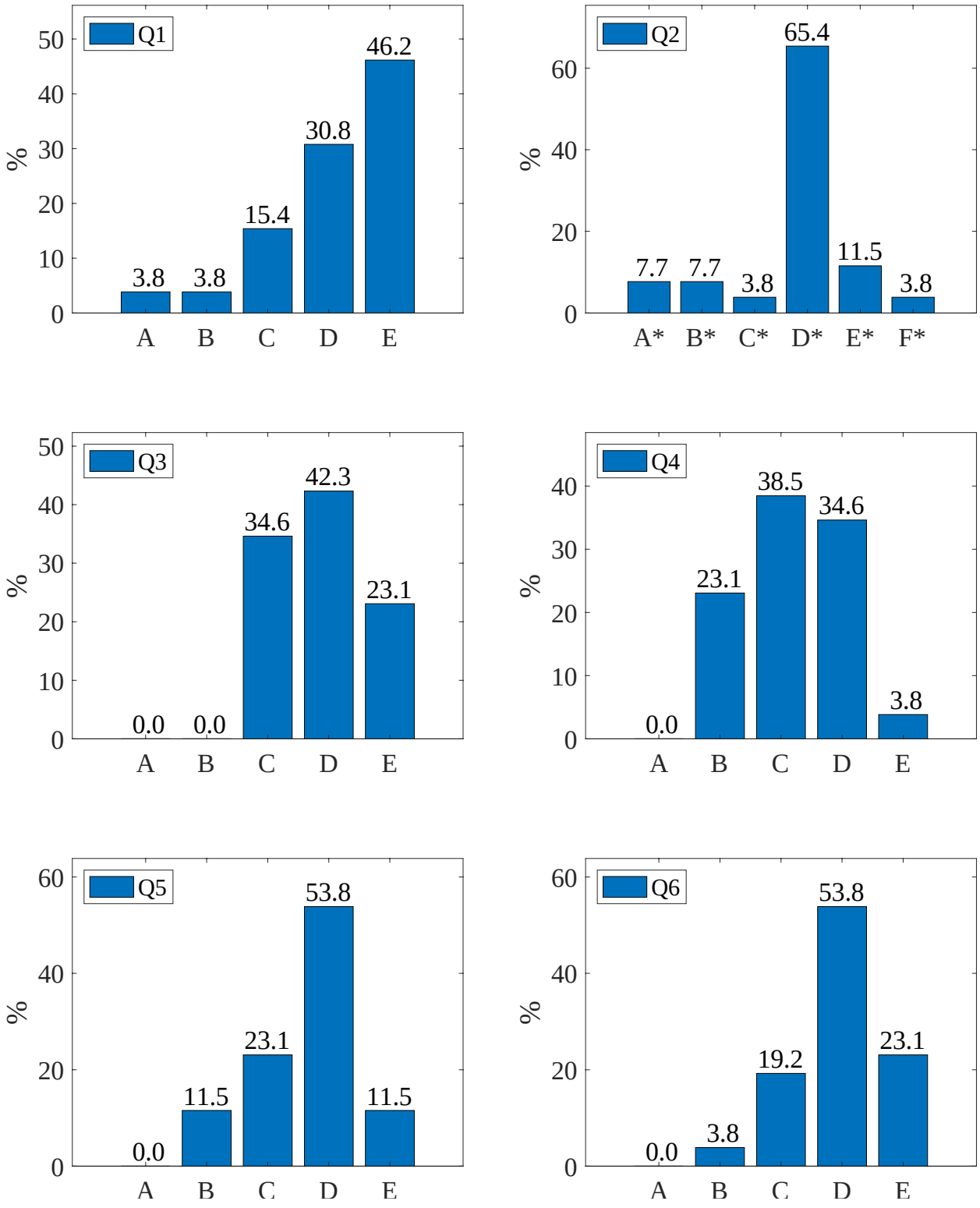

Figure 2 - Student responses to the survey questions.

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

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

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

Conclusions and Future Work

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

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

References

[1] Dugas, René. *A history of mechanics*. Courier Corporation, 2012.

[2] Sithole, Alec, Edward T. Chiyaka, Peter McCarthy, Davison M. Mupinga, Brian K. Bucklein, and Joachim Kibirige. "Student attraction, persistence and retention in STEM programs: Successes and continuing challenges." *Higher Education Studies* 7, no. 1, 2017, 46-59.

[3] Kolmos, A., 2009. Problem-based and project-based learning: Institutional and global change. *University science and mathematics education in transition*, 261-280.

[4] Kirschner, P.A., Sweller, J. and Clark, R.E., 2006. Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational psychologist*, *41*(2), pp.75-86.

[5] Kolb, D.A., 2014. *Experiential learning: Experience as the source of learning and development*. FT press.

[6] Laal, Marjan, and Seyed Mohammad Ghodsi. "Benefits of collaborative learning." *Procedia-social and behavioral sciences* 31, 2012, 486-490.

[7] Vickrey, T., Rosploch, K., Rahmanian, R., Pilarz, M. and Stains, M., 2015. Research-based implementation of peer instruction: A literature review. *CBE—Life Sciences Education*, *14*(1), p.es3.

[8] Cortright, R.N., Collins, H.L. and DiCarlo, S.E., 2005. Peer instruction enhanced meaningful learning: ability to solve novel problems. *Advances in physiology education*, *29*(2), pp.107-111.

[9] Duran, David. "Learning-by-teaching. Evidence and implications as a pedagogical mechanism." *Innovations in Education and Teaching International* 54, no. 5, 2017, 476-484.

[10] 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.