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In-class instructor demonstrations improve students' conceptual understanding of undergraduate engineering dynamics

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ABSTRACT: More attention is being paid to instructor demonstrations when learning multiple subjects, such as mathematics, physics, chemistry and engineering. In this article, the author describes employing in-class instructor demonstrations to improve students' conceptual understanding of engineering dynamics, a foundation undergraduate course. A quasi-experimental research study with pre- and post-tests was conducted on a control group and intervention group, the intervention being instructor demonstrations. Statistical analysis was performed on pre- and post-test scores for each group. Learning gains and effect size were calculated followed by a description of student responses to a questionnaire administrated on the intervention group after the post-test. The results show that after in-class instructor demonstrations, students overall in the intervention group increased their conceptual understanding of engineering dynamics. The intervention had a moderate impact on student learning, with the effect size of 0.32. Eighty-four percent of the students surveyed provided positive comments on their learning experiences with instructor demonstrations.

Keywords: In-class instructor demonstrations, conceptual understanding, undergraduate engineering dynamics

INTRODUCTION

Engineering dynamics is a foundation second-year undergraduate course required in many engineering programmes; for example, mechanical, aerospace, mechanics, civil and environmental engineering. This course covers a wide range of fundamental concepts, such as velocity, acceleration, motion, friction, force, impulse, momentum, work and energy [1][2]. Students must have strong mental visualisation skills to understand and master these concepts. Therefore, this course is challenging for many students.

Research has shown that students have a variety of learning styles [3][4]. The Felder-Silverman learning style model includes four dimensions of learning styles, viz. active vs reflective, visual vs verbal, sensing vs intuitive and sequential vs global [4]. The visual-verbal dimension deals with how students prefer information to be presented. Relevant research shows that the majority of students are visual learners [5], i.e. they prefer information to be presented in a visual form, such as diagrams, charts, pictures, physical and virtual objects.

To help students visualise physical phenomena to understand important concepts, a variety of techniques have been developed; for example, computer simulations, animations, real-world laboratory experiments and instructor demonstrations [6-11]. Among these techniques, instructor demonstrations have in recent years received growing attention [12-14]. By observing and interacting with instructor demonstrations, students can develop a better grasp of concepts that are difficult to understand through the instructor's verbal descriptions alone [15][16].

Instructor demonstrations have been widely employed in teaching and in learning multiple subject matter and disciplines, such as mathematics, physics, chemistry and engineering, in a variety of educational settings. Basheer et al conducted an experimental study to investigate the effectiveness of teachers' demonstrations in enhancing middle-school students' understanding of the oxidation-reduction concept [12]. They reported that students in the experimental group performed statistically significantly better than their control group counterparts. Their research has also shown that teachers' demonstrations increased students' interest and motivation to learn chemistry.

Through pre- and post-tests, McKee et al compared conceptual understanding of students in two groups: a group who performed laboratory experiments and a group who reviewed the demonstration of laboratory experiments [15]. They reported that the two learning methods did not result in a statistically significant difference in students' conceptual understanding. Kresta also argued that hands-on demonstrations can be used as an alternative to full-scale laboratory experiments [16].

The goal of the present study was to investigate the effect of in-class instructor demonstrations on students' conceptual understanding of an engineering dynamics course. In this article, the author describes the research method employed in this study and the method of data collection. Example multiple-choice questions employed in pre- and post-tests on the control and intervention groups are illustrated. Statistical analysis was performed to compare students' pre- and post-test scores for each group. Learning gains and effect size were calculated, followed by a description of student responses to a questionnaire survey administrated on the intervention group. Conclusions are drawn at the end of the article.

RESEARCH METHOD

The research question of the present study was: to what extent did in-class instructor demonstrations improve students' conceptual understanding of undergraduate engineering dynamics? To answer this question, a quasi-experimental research study was performed, involving pre- and post-tests, on two groups of students: 1) a control group taught without in-class instructor demonstrations; and 2) an intervention group taught through in-class instructor demonstrations, such as illustrating the projectile motion of a ball and the motion of bicycle wheels. Both groups were taught by the same instructor (i.e. the author of this article) and had the same course syllabus.

STUDENT PARTICIPANTS

All student participants were second-year undergraduates in the College of Engineering at a public research institution in the USA. Table 1 shows the number of student participants in pre- and post-tests in each group. The majority of students were either mechanical and aerospace engineering majors or civil and environmental engineering majors.

Table 1: Number of student participants.

Group	Pre-test	Post-test
Control group	107	81
Intervention group	77	73

DATA COLLECTION

The focus of the study was on several important concepts in particle dynamics, including the directions of acceleration components (i.e. tangential, normal, radial and transverse accelerations), as well as the direction of friction. The assessment instrument used in pre-tests and post-tests consisted of four multiple-choice conceptual questions. These questions were posted on-line, and students responded anonymously to these questions.

Below are two sample conceptual questions, where question 2 was an assessment whether students understand the directions of radial and transverse acceleration components in a projectile motion, and question 4 was an assessment whether students understand the directions of frictional forces acting on the front and rear wheels of a car. Although students often are confused about these important concepts, they were not addressed in either dynamics concept inventory [17][18] or force concept inventory [19].

Question 2: A ball is shot from starting point O to ending point E, as shown in Figure 1. A polar co-ordinate system, with the origin at point O, is employed to analyse the motion of the ball. Let a_r and a_θ be its radial and transverse components of acceleration, respectively. Ignore air resistance. While the ball is at two different positions along its path, which one of the following figures correctly shows the directions of a_r and a_θ? a) Figure 1a; b) Figure 1b; c) Figure 1c; or d) Figure 1d.

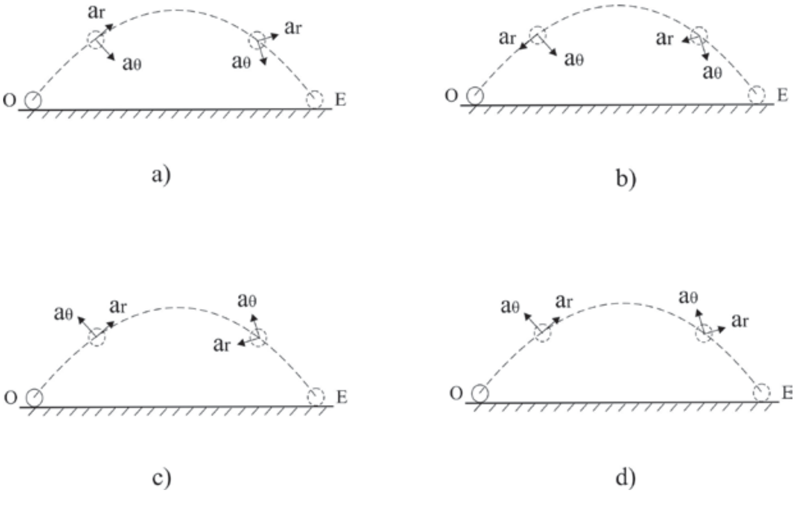

Figure 1: The directions of radial and transverse acceleration components.

Question 4: A rear-wheel drive (RWD) car (i.e. the engine drives rear wheels only) moves along a rough road, as shown in Figure 2. Which one of the following figures correctly shows the directions of frictional forces acting on the front and rear wheels of the car? a) Figure 2a; b) Figure 2b; c) Figure 2c; or d) Figure 2d.

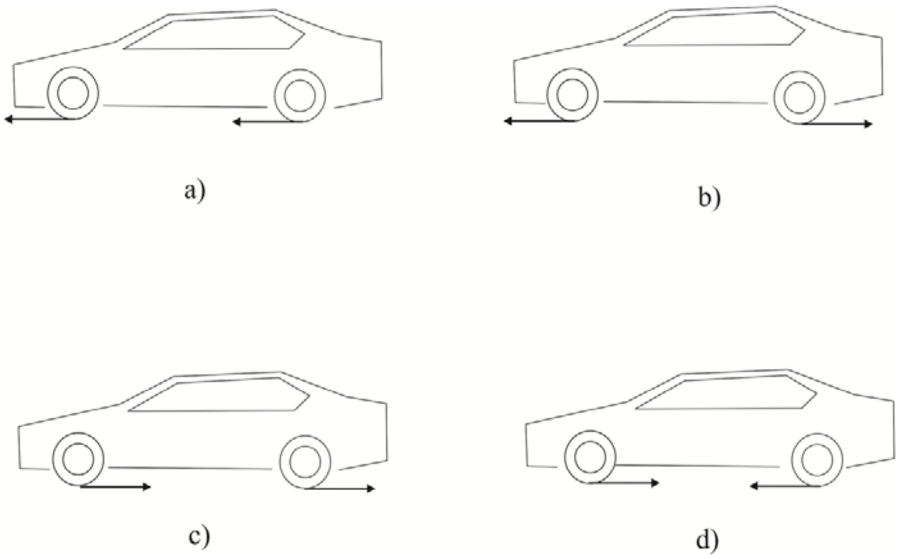

Figure 2: The directions of frictional forces acting on the front and rear wheels of the car.

RESULTS AND ANALYSIS

Statistical Analysis

Table 2 shows the results of statistical descriptive analysis. As can be seen from Table 2, students' pre-test scores were very close (1.33 vs 1.35) between the control and intervention groups, despite the control group (n = 107) having more students than the intervention group (n = 77). The results of independent-samples *t*-test ($t = -0.130$, $p = 0.897$) further confirmed there was no statistically significant difference in pre-test scores between the control and intervention groups. This means that in terms of their pre-test scores, the control and intervention groups were comparable.

Table 2: Statistical descriptive analysis of students' pre- and post-test scores.

Group	Pre-test		Post-test	
	Mean	SD	Mean	SD
Control group	1.33	1.20	1.88	1.23
Intervention group	1.35	1.23	2.18	1.27

Tables 3 to 7 show the percentages of students choosing answers in the pre- and post-tests of control and intervention groups. The correct answers to Questions 1, 2, 3 and 4 are d, b, b and d, respectively. The percentages of students choosing the correct answer to each question are in bold type in Tables 3 to 6.

In the majority of cases, the percentage of students choosing the correct answer to each question in the post-test was greater than that in the pre-test. The only exception was question 1 for the control group, where 22.4% of the students chose the correct answer, d, in the pre-test (Table 3) and only 17.3% in the post-test (Table 4).

A close examination of the results in Tables 5 and Table 6 shows that after the intervention, i.e. in-class instructor demonstrations, students overall in the intervention group increased their understanding of all concepts assessed. For example, the percentage of students choosing the correct answer to question 4 increased, from 40.3% in the pre-test to 76.7% in the post-test. The results of independent-samples *t*-test ($t = -4.044$, $p = 0.000$) further confirmed there was a statistically significant difference between pre-test and post-test scores of the intervention group.

Table 3: Percentages of students choosing answers in the pre-test of control group.

Answer choice	Question 1	Question 2	Question 3	Question 4
a	67.3%	27.1%	28.0%	27.1%
b	2.8%	27.1%	43.0%	6.5%
c	7.5%	19.6%	25.2%	23.4%
d	22.4%	26.2%	3.7%	43.0%

Table 4: Percentages of students choosing answers in the post-test of control group.

Answer choice	Question 1	Question 2	Question 3	Question 4
a	80.2%	39.5%	16.0%	12.3%
b	1.2%	34.6%	67.9%	7.4%
c	1.2%	4.9%	9.9%	12.3%
d	17.3%	21.0%	6.2%	67.9%

Table 5: Percentages of students choosing answers in the pre-test of the intervention group.

Answer choice	Question 1	Question 2	Question 3	Question 4
a	54.5%	48.1%	23.4%	22.1%
b	2.6%	23.4%	39.0%	15.6%
c	9.1%	11.7%	26.0%	22.1%
d	33.8%	16.9%	11.7%	40.3%

Table 6: Percentages of students choosing answers in the post-test of intervention group.

Answer choice	Question 1	Question 2	Question 3	Question 4
a	54.8%	45.2%	11.0%	8.2%
b	1.4%	34.2%	72.6%	9.6%
c	8.2%	8.2%	5.5%	5.5%
d	35.6%	12.3%	11.0%	76.7%

Group-average Learning Gain

For each group of students, group-average learning gain was calculated as [20]:

$$\text{Group-average learning gain} = \frac{\text{Group-average posttest score (\%) - Group-average pretest score (\%)}}{\text{100\% - Group-average pretest score (\%)}} \quad (1)$$

Table 7 shows the comparison of group-average learning gain for each question between the control and intervention groups. As seen from Table 7, the intervention group outperformed the control group in answering questions 1, 2 and 4, especially question 4 (61.0% vs. 43.7%). The two groups had nearly equal performance (55.1% vs 57.1%) in answering question 2.

Table 7: Group-average learning gain.

Group	Question 1	Question 2	Question 3	Question 4
Control group	-6.6%	10.3%	57.1%	43.7%
Intervention group	2.8%	14.2%	55.1%	61.0%

Effect Size

Effect size is a quantitative measure of the impact of an intervention. It can be estimated as suggest Rosnow et al [21]:

$$\text{Effect size} = \sqrt{\frac{t^2}{t^2 + df}} \ \ldots \quad (2)$$

Where: t is the t-value and df is the degrees of freedom. Based on Equation (2), the intervention described in the present study had an effect size of 0.32, which represented a moderate impact.

Questionnaire Survey

For the students in the intervention group, an anonymous questionnaire survey was administrated after the post-test. A total of 68 students responded to the survey and were asked to describe their experiences with instructor demonstrations. Figure 3 shows their responses to a Likert-scale question that indicated their level of agreement with the following statement: Overall, in-class instructor demonstrations helped improve your conceptual understanding in engineering dynamics: A) strongly disagree; B) disagree; C) neutral; D) agree; and E) strongly agree.

As seen from Figure 3, 84% of the students surveyed indicated they *agreed* or *strongly agreed* that in-class hands-on demonstrations helped improve their conceptual understanding. Although student perceptions (shown in Figure 3) do not accurately represent student learning outcomes (shown in Table 6), student perceptions directly affect students' motivation and interest in learning [22].

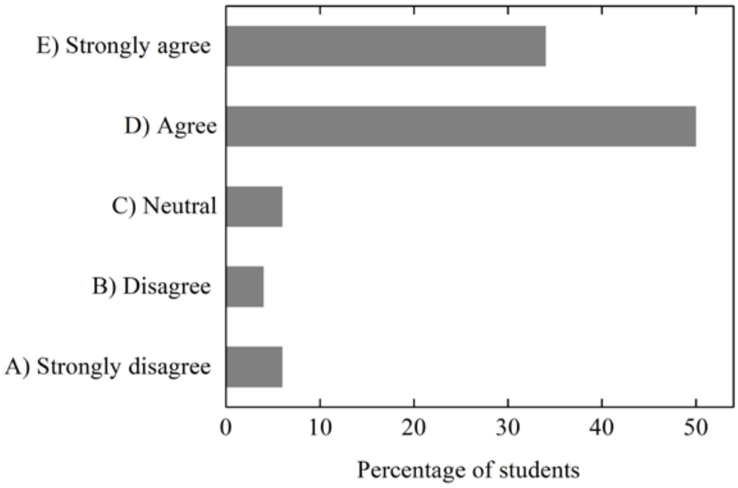

Figure 3: Students' responses to a Likert-scale question.

The paragraphs below list representative students' comments on in-class instructor demonstrations:

- *The bike example helped me to understand the directions of friction on a wheel that was the driving wheel or the following wheel. I was not able to picture the natural motion of a wheel compared to a wheel on a surface with friction without the demonstration.*
- *It can be hard to visualise and understand what is going on when reading words on a paper, but when we are shown a physical demonstration of the principles in action, it makes it easy to see and understand what is happening.*
- *I am a visual learner, so seeing concepts applied really helps me to grasp what is going on.*
- *It gives you a visual representation you can see and remember, not just a diagram in a book.*
- *It helped to visualise the direction forces were going.*
- *I am more of a visual hands-on learner. Seeing the concepts in action helped me understand and remember them easier.*
- *Having a visual representation of the concepts we discussed solidifies and clarifies what is happening.*

CONCLUSIONS

Described in this article are the assessment results of employing in-class instructor demonstrations to improve students' conceptual understanding in a foundation undergraduate engineering dynamics course. Through the quasi-experimental research study that involved pre- and post-tests on the control and intervention groups, it was found that in-class instructor demonstrations increased students' understanding of important concepts addressed in the present study, including the directions of acceleration components and the directions of frictional forces.

Independent-samples t-test (t = -4.044, p = 0.000) confirmed a statistically significant difference between pre-test and post-test scores of the intervention group. In terms of group-average learning gain, the intervention group outperformed the control group in answering three assessment questions. Both groups had nearly equal performance in answering an additional question. The intervention had a moderate impact on student learning, with the effect size of 0.32.

Based on the findings of the study, it is suggested that instructor demonstrations be implemented as a supplemental tool to assist in teaching and learning engineering dynamics. However, instructor demonstrations should not be used as the sole method. Other methods should also be employed to address the diverse needs of students.

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BIOGRAPHY

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