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Reducing Students' Conceptual Misunderstanding in Engineering Dynamics Through Enhanced Hands-on Experimentation*

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Conceptual understanding is critical for students' learning of many subject matters in science and engineering. This paper describes an educational intervention called enhanced hands-on experimentation (EHE). The goal is to reduce students' conceptual misunderstanding in engineering dynamics, a foundational second-year course that undergraduates in many engineering programs are required to take. Two case studies were conducted to compare the effectiveness of EHE in reducing students' conceptual misunderstanding with that of traditional textbook instruction (TTI). Pre- and post-tests were administered on EHE and TTI student groups in both case studies. A think-aloud approach was employed to collect qualitative verbal data generated by 48 students with 1,248 student responses. By quantifying qualitative verbal data collected, enhanced hands-on experimentation was found to be more effective than traditional textbook instruction in reducing students' conceptual misunderstanding in engineering dynamics.

Keywords: students' conceptual misunderstanding; enhanced hands-on experimentation (EHE); traditional textbook instruction (TTI); engineering dynamics

1. Introduction

1.1 Students' conceptual misunderstanding in engineering dynamics

A solid conceptual understanding is important and essential for students to learn many subject matters in science and engineering [1]. Research evidence has revealed a strong correlation between students' conceptual understanding and their problem-solving skills [2, 3]. Research evidence has also illustrated students' conceptual misunderstanding on many subject matters in science and engineering [4–6]. In her widely-cited cognitive and psychological study, Chi [6] pointed out that students' misconceptions can be robust and hard to change if students themselves cannot "recognize and understand a variety of emergent processes for which they have robust misconceptions."

Engineering dynamics is a foundational second-year course that undergraduates in many engineering programs, e.g., mechanical, aerospace, civil, and environmental engineering, are required to take. This required course covers numerous fundamental concepts in engineering and physics mechanics, e.g., force, motion, velocity, acceleration, work, energy, impulse, and momentum [7]. Research has studied students' perceptions of difficult concepts in engineering dynamics [8, 9] and students' misunderstanding about important concepts, such as force and motion [10–15] and impulse and momentum [16, 17]. A variety of concept inventories have also been developed to assess and identify students' conceptual misunderstanding in engineering dynamics [18, 19] and in related physics mechanics [20–22].

For example, Rosenblatt, Sayre and Heckler [13] developed a multiple-choice instrument including a set of conceptual questions to assess students' understanding of all relationships among force, velocity, and acceleration. They found that students had a directional and hierarchical understanding of the relations among these three concepts. Students mistakenly believed that "velocity implies force more than force implies velocity" [13]. Thornton and Sokoloff [15] employed a research-based, multiple-choice instrument called Force and Motion Conceptual Evaluation to assess students' understanding of Newton's Laws of Motion. They reported that many students taught by traditional instruction did not commonly understand kinematics and dynamics concepts [15].

Rosa, Cari, Aminah and Handhika [16] employed tests and interviews to study students' understanding level and scientific literacy competencies of impulse and momentum concepts. Student participants were determined using a random sampling technique. The researchers [16] reported that students had conceptual misunderstanding, even if the material had been previously taught. Dalaklioğlu, Demirci and Sekercioğlu [17] implemented an Energy and Momentum Conceptual Survey test to assess students' understanding of

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energy and momentum concepts. They found that students had many misconceptions related to energy and momentum and could not recognize the significance of the relationship between these two concepts. Students had difficulty in "qualitatively interpreting the basic principles related to energy and momentum and in applying them in physical situations" [17].

1.2 Educational interventions for reducing students' conceptual misunderstanding in engineering dynamics

A variety of educational interventions have been developed in order to reduce and correct students' conceptual misunderstanding in engineering dynamics [23–27]. Schmidt [24] incorporated peer instruction into an introductory engineering dynamics course to increase students' conceptual understanding. Peer instruction was facilitated by an audience response system (nicknamed clickers) and enabled students to conduct a more critical and realistic self-assessment of their conceptual understanding. The clicker questions were designed to expose conceptual misunderstanding among students. Thus, the instructor could provide just-in-time instruction to correct students' misunderstanding of relevant concepts.

Enriquez [25] conducted an experimental study to investigate how Tablet PCs and wireless technology could be employed in a large engineering dynamics classroom to promote active and interactive learning. He reported that students' learning outcomes, including students' conceptual understanding, were improved as a result of active and interactive learning. Students in the experimental group performed better than those in the comparison group in many aspects including quizzes, homework assignments, tests, and the final exam.

Stanley [26] developed an interactive web-based computer animation software to enhance students' fundamental conceptual understanding of particle kinematics and kinetics, two important learning topics covered in engineering dynamics. His software enables students to visualize the motion of a particle and help correct students' conceptual misunderstanding of the relationship between force and motion.

1.3 The innovation and contribution of the present study

In the present study, enhanced hands-on experimentation (EHE) was developed and assessed to reduce students' conceptual misunderstanding in engineering dynamics. Hands-on learning has been widely employed in the teaching and learning of engineering subjects [28–31]. Golter, Van Wie and Nazempour [30] compared the effectiveness of hands-on learning vs. traditional lectures in teaching about shell and tube heat exchanges in a junior level Chemical Engineering Fluid Mechanics and Heat Transfer course. The class was split into two sections with one section taught with hands-on learning and another taught with traditional lectures. The researchers [30] reported that compared to traditional lectures, hands-on learning enhanced students' understanding of what was physically happening with a shell and tube heat exchanger and the difference between theoretical and experimental heat fluxes.

The innovation and contribution of the present study is enhanced hands-on experimentation (EHE), where additional learning materials, including relevant experimental graphics and associated interactive instruction, were incorporated into hands-on experimentation to enhance students' conceptual understanding. Two case studies were conducted in the present study to compare the effectiveness of EHE in reducing students' conceptual misunderstanding with that of traditional textbook instruction (TTI). New research findings were generated by quantifying qualitative verbal data collected through a think-aloud approach.

In the remaining sections of this paper, overall research design and student participants are described. Representative examples of both hands-on experimentation (EHE) and traditional textbook instruction (TTI) are provided. The assessment instruments developed for and employed in pre- and post-tests in two case studies are introduced, followed by a description of method of data collection and analysis. Research findings generated from the present study are presented, analyzed, and discussed. Conclusions are made at the end of the paper.

2. Research and data analysis methods

2.1 Overall research design and student participants

The research question of the present study is: How effective is enhanced hands-on experimentation (EHE), compared to traditional textbook instruction (TTI), in reducing students' conceptual misunderstanding in engineering dynamics? Two case studies were conducted to answer this research question. The first case study focuses on the concepts of force and acceleration, and the second case on the concepts of impulse and momentum. All of these are critical concepts covered in engineering dynamics.

Table 1 shows the overall research design. Learning modules I and II were developed and employed in the first and second case study, respectively. For each learning module, two student groups were

Table 1. Overall research design

Learning modules	Interventions	Student groups	Number of students	Assessment instruments used in pre- and post-test
I: Force and acceleration	Enhanced hands-on experimentation (EHE) I	EHE group I	12	Assessment instrument I
I: Force and acceleration	Traditional textbook instruction (TTI) I	TTI group I	12	Assessment instrument I
II: Impulse and momentum	Enhanced hands-on experimentation (EHE) II	EHE group II	12	Assessment instrument II
II: Impulse and momentum	Traditional textbook instruction (TTI) II	TTI group II	12	Assessment instrument II

involved: an enhanced hands-on experimentation (EHE) group and a traditional textbook instruction (TTI) group. Each group had 12 students. A total of 48 student participants in four groups were involved: EHE group I, TTI group I, EHE group II, and TTI group II.

All student participants were recruited from those who were taking a second-year Engineering Dynamics class taught by the first author of this paper. The vast majority of students were either Mechanical and Aerospace Engineering majors or Civil and Environmental Engineering majors. The convenience and maximum variety sampling strategy [32–34] was employed for student recruitment and selection. First, email invitations were sent to all students in the class. Those who responded to email invitations were stratified by their graduate point average (GPA) and the average scores of their prior mid-term examinations in engineering dynamics. Before participating in the present study, students had taken two mid-term examinations on particle kinematics and kinetics in the Dynamics course. The average score of each student's mid-term examinations was calculated and was employed along with his/her GPA to determine the level of his/her academic performance: low, medium, and high. Efforts were made to ensure that students with different levels of academic performance were included in the present study. Then, students were

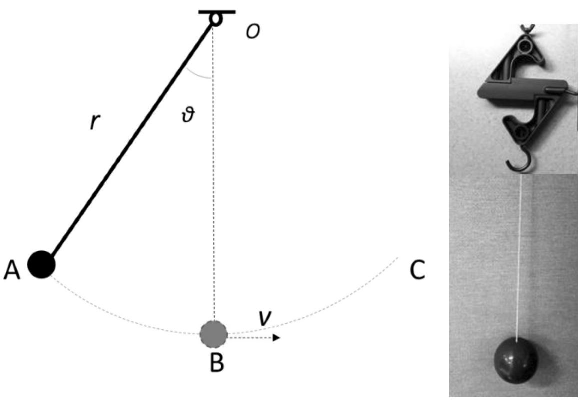


Fig. 1. Pendulum with a force sensor.

randomly assigned into enhanced hands-on experimentation (EHE) groups I and II and traditional textbook instruction (TTI) groups I and II for two case studies.

2.2 *Enhanced hands-on experimentation*

Enhanced hands-on experimentation (EHE) was developed for each learning module. Figure 1 shows an EHE developed for learning module I. This EHE involves the concepts of force and two components of acceleration: normal and tangential acceleration. As shown in Fig. 1, a pendulum swings between positions A and C. Its lowest position is at position B. A force sensor was employed to measure the tension force in the rope. The cyclical variation of the tension force at different positions is shown in Fig. 2. The tension force is the largest at position B and the smallest at positions A and C.

Students were provided further interactive instruction on how Newton's second law can be employed to set up mathematical equations to determine the tension forces at positions A, B, and C. Doing so helped students develop a better understanding of how physical phenomena they had observed were associated with dynamics concepts behind these phenomena.

Figure 3 shows an EHE developed for learning module II. Fig. 3 shows the EHE developed for learning module II. This EHE involves the concepts of linear impulse and linear momentum. As shown in Fig. 3, a basketball and a dough ball are dropped from the same height with the same initial speed of zero. They have the same speed v_1 immediately before they hit a force plate placed on the ground. After hitting, they bounce back with different speeds v_2. The forces that the basketball and dough balls apply to the force plate were measured, as shown in Fig. 4. The force that the basketball applies to the force plate can be greater than 160 N. In contrast, the force that the dough ball applies to the force plate is less than 140 N.

Students were provided further interactive instruction on how the principle of linear impulse and momentum could be employed to set up math-

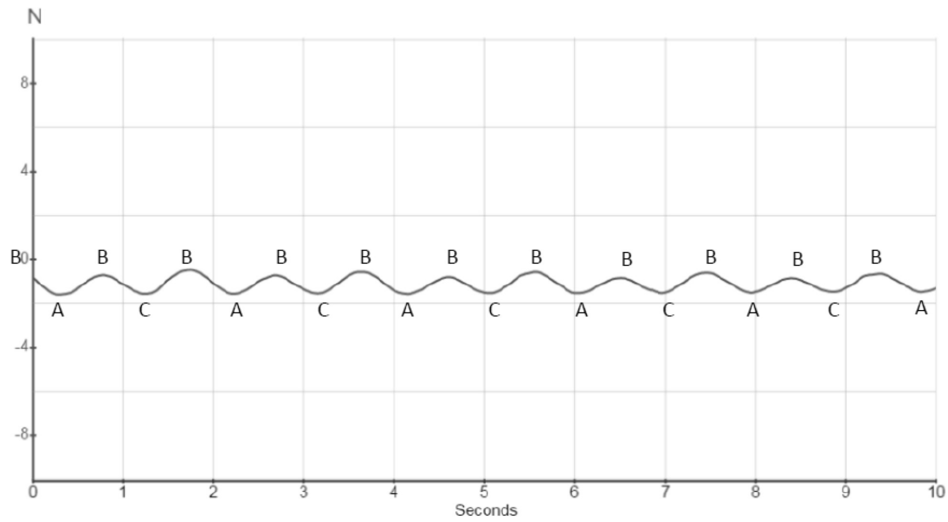


Fig. 2. Cyclical variation of the tension force in the rope at different positions.

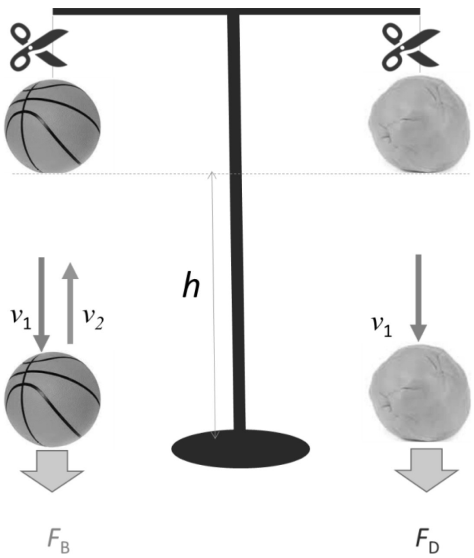


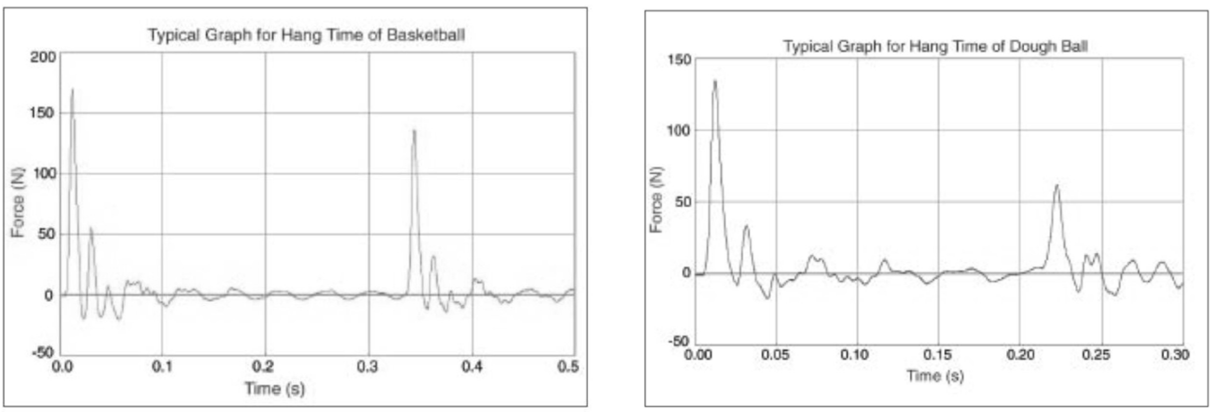
Fig. 3. Dropping of a basketball (left) and a dough ball (right).

ematical equations to solve the dynamics problem shown in Fig. 3. Students were taught that momentum is a vector and its direction matters.

2.3 Traditional textbook instruction

The material excerpted from a traditional textbook for engineering dynamics [7] was provided to two TTI groups for them to learn and relearn the concepts of force and acceleration and the concepts of impulse and momentum, respectively. The following paragraphs show two representative examples of the instruction materials excerpted from the textbook [7].

For the concepts of force and acceleration: "When a particle moves along a curved path which is known, the equation of motion for the particle may be written in the tangential, normal, and binormal directions. . . It is caused by ΣFn, which always acts in the positive n direction, i.e., toward the path's center of curvature. . ." [7].



(a) (b)

Fig. 4. The force measured via the force plate: (a) F_B > 160 N for the basketball and (b) F_D < 140 N for the dough ball.

For the concepts of impulse and momentum: "In this section, we will integrate the equation of motion with respect to time and thereby obtain the principle of impulse and momentum. The resulting equation will be useful for solving problems involving force, velocity, and time. . . Graphically the magnitude of the impulse can be represented by the shaded area under the curve of force versus time. . ." [7].

2.4 Assessment instruments employed in pre- and post-tests

Two assessment instruments—I and II—were developed for use in pre- and post-tests for two case studies. For the same case study, the assessment instrument employed in the pretest was the same as that employed in the post-test. Assessment instrument I consisted of 10 multiple-choice conceptual questions. Assessment instrument II included 16 multiple-choice conceptual questions. The following paragraphs provide three representative examples of multiple-choice questions.

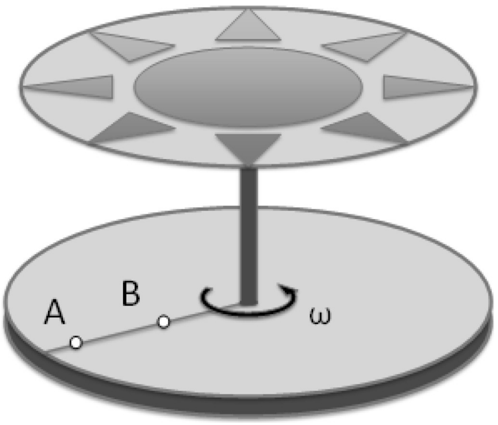


Fig. 5. An example kinematics assessment question employed in assessment instrument I.

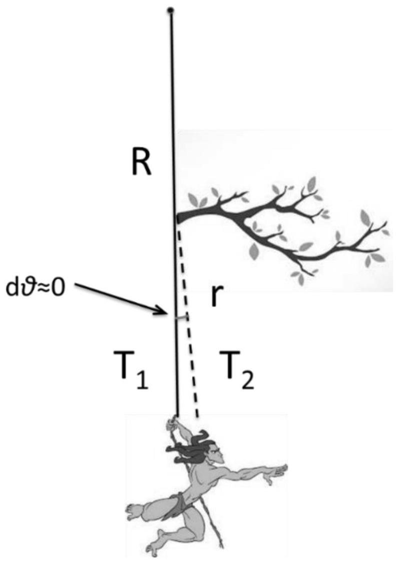


Fig. 6. An example kinetics assessment question employed in assessment instrument I.

Example kinematics question employed in assessment instrument I: Two riders A and B sit on the carousel shown in the figure to the right [see Fig. 5]. The carousel rotates at a constant angular velocity ω (omega). Which of the following relationships holds regarding the velocity V and acceleration a of riders A and B?

(A) $V_A > V_B$ and $a_A > a_B$
(B) $V_A > V_B$ and $a_A = a_B$
(C) $V_A > V_B$ and $a_A < a_B$
(D) $V_A = V_B$ and $a_A > a_B$
(E) $V_A = V_B$ and $a_A = a_B$

Example kinetics question employed in assessment instrument I: Tarzan swings down on a rope of length R (the swing radius) [see Fig. 6]. The rope hits a branch when the rope is perpendicular to the ground. The swing radius changes to r ($r = 0.5R$). Which of the following relationship holds regarding the tension in the rope immediately before it hits the branch (T_1) and the tension in the rope immediately after it hits the branch (T_2)?

(A) $T_1 > T_2$
(B) $T_1 = T_2$
(C) $T_1 < T_2$

Example question employed in assessment instrument II: Two identical car A and car B (with the same mass) run on a circular road at different speeds $V_A = 0.5\ V_B$. The radius of circular road for car A is R, while the radius of circular road for car B is r, and $R = 2r$ [see Fig. 7]. Which of the following statements is correct regarding car A and car B?

(A) In terms of magnitude, their linear momentums are the same but their angular momentums are different.
(B) In terms of magnitude, their linear momentums are different and their angular momentums are also different.
(C) In terms of direction, their linear momentums are the same but their angular momentums are different.
(D) In terms of direction, their linear momentums are different and their angular momentums are different also.

2.5 Method of data collection and analysis

All student participants completed pre- and post-tests in the two case studies. Instead of simply counting the number of multiple-choice questions a student participant answered correctly in pre- and post-tests, a think-aloud approach [35–37] was employed to collect qualitative verbal data in the tests to compare the effectiveness of EHE and TTI.

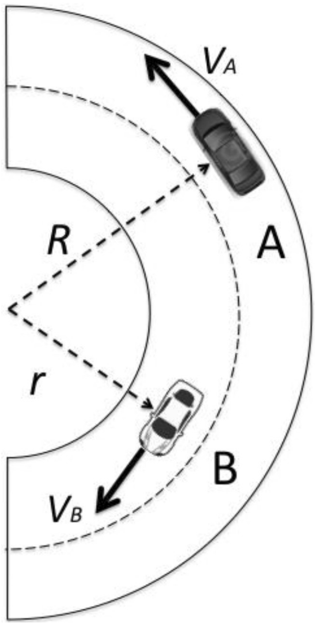


Fig. 7. An example assessment question employed in assessment instrument II (top view).

The reason for doing this is because a student might answer a multiple-choice question correctly based on his or her intuition and guess without solid scientific reasoning or a complete understanding. The think-aloud approach provides deep information on why a student selects a particular answer to a multiple-choice question, so as to detect the level of students' conceptual understanding and misunderstanding.

In the think-aloud approach, student participants spoke aloud whatever responses they had for each multiple-choice question in pre- and post-tests. Verbal data was audio-recorded for subsequent transcription and coding. Two coders were involved to ensure inter-coder reliability. Both coders were trained on how to code a transcript for qualitative research. The coders met a number of times during the coding process. Based on the initial coding tables, each coder coded a transcript independently and then compared their results with each other to discuss and solve any technical disagreements. In case they did not reach an agreement for coding particular verbal data, the third researcher joined conversations as a mediator. The coding process was iterative and time-consuming as the initial coding tables evolved. The iterative nature of the coding process is common and typical in qualitative research [32].

In the present study, the coding process was also labor intensive, due to 48 student participants being involved, 24 per case study, as shown in Table 1. In the first case study, each student responded to 20 multiple-choice questions in pre- and post-tests, with 10 questions in the pretest and the same 10 questions in the post-test. In the second case study, each student responded to 32 multiple-choice questions in pre- and post-tests, with 16 questions in the pretest and the same 16 questions in the post-test. If a student's verbal explanations of why he or she selected an answer to a particular multiple-choice question is defined as a student response, as many as 1,248 student responses were generated and coded from the present study.

Tables 2 and 3 show the final coding tables for categorizing students' conceptual misunderstand-

Table 2. Coding categories of student's misunderstanding identified through assessment instrument I

Coding categories	Coding subcategories	Descriptions
1. Preconceived misunderstanding	1.1 Daily life experiences	Students create misunderstanding from their daily life experiences or their intuition and guessing with no scientific reasoning.
	1.2 Velocity	Students do not understand the relationships and differences among speed, velocity, and angular velocity.
	1.3 Acceleration	Students do not understand the relationships and differences among speed, acceleration, and angular acceleration.
	1.4 Statics	Students do not understand force equilibrium and balanced forces.
2. Incomplete understanding of basic concepts	2.1 Acceleration direction	Students mistakenly think acceleration is always in the same, or parallel to, the direction of velocity.
	2.2 Physical meaning of normal acceleration	Students confuse normal acceleration with tangential acceleration and do not understand the change in the direction of acceleration.
3. Incorrect understanding of high-level concepts	3.1 Free-body & kinetic diagrams	Students performed incorrect analysis on free-body & kinetic diagrams.
	3.2 Mathematics incapability	Students conduct incorrect mathematic analysis.
4. Vernacular misunderstanding	4.1 Hints	Students neglect italic/bold /underlined words in the text.
	4.2 Description and graphs	Students skip part of the verbal and graphical description of a problem.
	4.3 Confused terms	Students are careless and use wrong terminology.

Table 3. Coding categories of student's misunderstanding identified through assessment instrument II

Coding categories	Coding subcategories	Descriptions
1. Preconceived misunderstanding	1.1 Daily life experiences	Students create misunderstanding from their daily life experiences or their intuition and guessing with no scientific reasoning.
	1.2 Momentum	Students do not understand the definitions of linear and/or angular momentum.
	1.3 Impulse	Students do not understand the definitions of linear and/or angular impulse.
	1.4 Force-momentum	Students mistakenly think force is momentum.
	1.5 Energy-momentum	Students mistakenly think energy is momentum.
2. Incomplete understanding of basic concepts	2.1 Direction of linear momentum	Students neglect the direction of linear momentum.
	2.2 Direction of angular momentum	Students neglect the direction of angular momentum.
	2.3 Direction of impulse	Students neglect the vector feature of impulse.
3. Incorrect understanding of high-level concepts	3.1 Conservation of momentum	Students mistakenly think momentum is always conserved.
	3.2 Conservation of energy	Students are confused with conservation of energy.
	3.3 Principle of impulse and momentum	Students have incorrect comprehension about the principle of impulse and momentum.
4. Vernacular misunderstanding	4.1 Hints	Students neglect italic/bold /underlined words in the text.
	4.2 Description and graphs	Students skip part of the verbal and graphical description of a problem.
	4.3 Confused terms	Students are careless and use wrong terminology.

ing identified through assessment instrument I and II, respectively. These final coding tables were based on an extensive literature review about students' conceptual misunderstanding of engineering dynamics and relevant physics mechanics [10–17] as well as the iterative analysis of students' conceptual misunderstanding in two case studies.

The four coding categories shown in Tables 2 and 3 are the same: preconceived misunderstanding, incomplete understanding of basic concepts, incorrect understanding of high-level concepts, and vernacular misunderstanding. Each coding category has different coding subcategories, depending on the technical context involved in the case study. For example, in the first case study, which corresponds to assessment instrument I, the "incomplete understanding of basic concepts" coding category consists of two coding subcategories: acceleration direction and physical meaning of normal acceleration. In the second case study, which corresponds to assessment instrument II, the "incomplete understanding of basic concepts" coding category consists of three coding subcategories: direction of linear momentum, direction of angular momentum, and direction of impulse. The meaning of each coding subcategory is also provided in Tables 2 and 3.

To quantify qualitative verbal data collected in pre- and post-tests through the think-aloud approach [37], Tables 2 and 3 were employed to determine the numbers of students' misunderstanding instances in each pretest and post-test. The reduction in the number of students' misunderstanding instances was calculated by abstracting the number of students' misunderstanding instances in the pretest from that in the post-test. The reduction rate of students' misunderstanding instances was calculated as

$$\text{Reduction rate (\%)} = \frac{\text{Reduction in the number of students' misunderstanding instances}}{\text{The number of students' misunderstanding instances in the pretest}}$$

3. Results and analysis

Table 4 summarizes the number of misunderstanding instances in the pretest and post-test for four groups: EHE group I, TTI group I, EHE group II, and TTI group II. Four coding categories are listed in the first column in Table 4.

The data listed in Table 4 was further employed to generate Figs. 8 and 9 in order to graphically illustrate the effect of enhanced hands-on experimentation (EHE) on student learning. Fig. 8 shows the comparison of reductions in the number of students' misunderstanding instances for learning modules I and II. As can be seen from Fig. 8, students in EHE groups (I and II) had a higher

Table 4. Misunderstanding instances in the pretest and post-test for four groups

	Misunderstanding instances in the pretest				Misunderstanding instances in the post-test			
Coding categories	EHE group I	TTI group I	EHE group II	TTI group II	EHE group I	TTI group I	EHE group II	TTI group II
1. Preconceived misunderstanding	36	22	31	50	18	13	9	30
2. Incomplete understanding of basic concepts	29	25	16	18	16	21	5	8
3. Incorrect understanding of high-level concepts	5	9	32	30	2	4	19	18
4. Vernacular misunderstanding	20	13	12	14	13	10	3	11
Sub-total	90	69	91	112	49	48	36	67

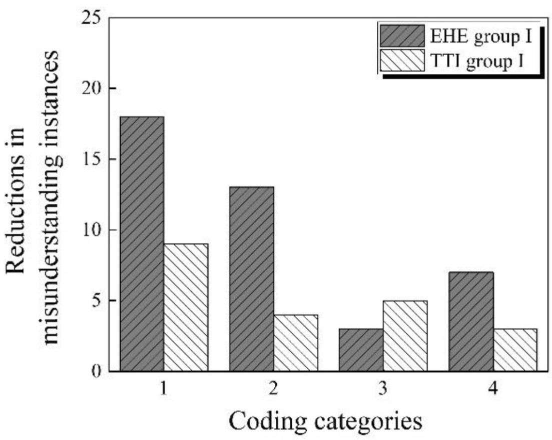
number of reductions in misunderstanding instances than students in TTI groups (I and II) had in all coding categories, except for coding category No. 3 for learning module I. This is because for learning module I, students in EHE group I had only 5 misunderstanding instances in the pretest; while students in EEI group I had 9 misunderstanding instances in the pretest. The number of misunderstanding instances in the pretest affects the reductions in misunderstanding instances.

Figure 9 shows the comparison of reduction rates for learning modules I and II. We can assign the difference in reduction rates between EHE group I and TTI group I, or between EHE group II and TTI group II, into three levels: slight difference (0–9.9%), moderate difference (10–19.9%), and significant difference (equal to or greater than 20%). Based on Fig. 8, the difference in reduction rates is:

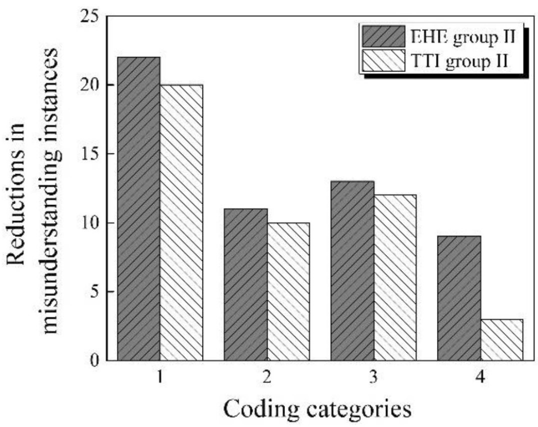
- Significant for coding category No. 2 for learning module I (28.8%), coding category No. 1 for learning module II (31%), and coding category No. 4 for learning module II (20.2%).
- Moderate for coding category No. 1 for learning module I (10.9%), coding category No. 4 for learning module I (11.9%), and coding category No. 2 for learning module II (13.2%).
- Slight for coding category No. 3 for learning module I (4.4%) and coding category No. 3 for learning module II (0.6%).

4. Discussions

In two case studies that involved a total of 8 coding categories, with 4 coding categories per case study as shown in Figs. 9(a) and 9(b), the difference in reduction rates between EHE and TTI groups is either significant or moderate for 6 coding categories. This demonstrates that on the whole, enhanced hands-on experimentation (EHE) is more effective than traditional textbook instruction



(a)



(b)

Fig. 8. Comparison of reductions in misunderstanding instances: (a) learning module I and (b) learning module II.

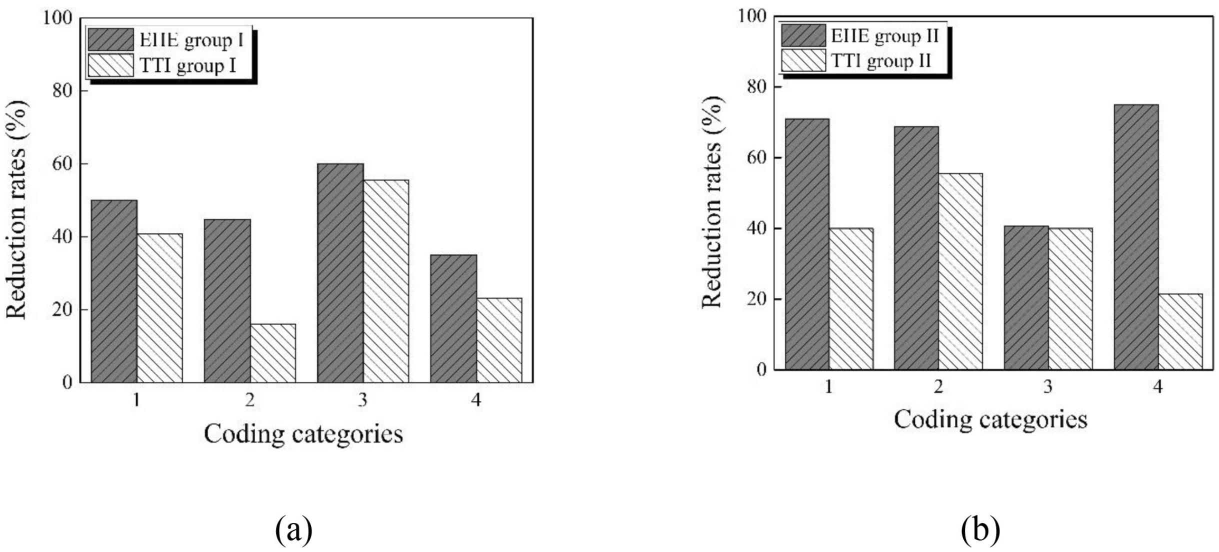


Fig. 9. Comparison of reduction rates: (a) learning module I and (b) learning module II.

(TTI) in reducing students' conceptual misunderstanding in engineering dynamics.

However, the difference in reduction rates between EHE and TTI groups are slight for the same coding category No. 3 in both case studies. As shown in Tables 2 and 3, coding category No. 3 is students' incorrect understanding of high-level concepts. In the first case study, coding category No. 3 included two coding subcategories: free-body & kinetic diagrams and mathematics incapability. In the second case study, coding category No. 3 included three coding subcategories: conservation of momentum, conservation of energy, and principle of impulse and momentum.

In other words, EHE is not effective in reducing students' incorrect understanding of high-level concepts. One possible reason is the level of difficulty of understanding high-level concepts. High-level concepts not only involve two or more basic (low-level) concepts, but also involve the relationship among basic (low-level) concepts. For instance, the principle of impulse and momentum, a high-level concept, involves two basic concepts of impulse and momentum. It also involves the relationship between the basic concepts of impulse and momentum. The relationship can be complex in situations where vector mechanics and curvilinear motion are involved.

Fang [8] recently studied students' perceptions of difficult concepts in engineering dynamics and found that laws and principles in engineering dynamics are among the concepts that students perceived as most difficult to understand. The laws and principles in engineering dynamics are all high-level concepts. For example, one student commented that "I'm having a hard time knowing when to use these concepts [i.e., impulse and momentum] to solve a problem. I have the general idea of what needs to happen but I have a hard time remembering how to set up the diagrams" [8].

Other educational interventions would be needed to supplement enhanced hands-on experimentation (EHE) to reduce students' incorrect understanding of high-level concepts. These supplemental educational interventions might be either extant interventions [23–27], such as modern education technology like computer animations, or new interventions. An in-depth study of other educational interventions is beyond the scope of this paper and will be included in future work.

5. Conclusions

This paper has described the development and assessment of enhanced hands-on experimentation (EHE) to reduce students' conceptual misunderstanding in engineering dynamics, a foundational second-year course that undergraduates in many engineering programs are required to take. Two case studies were conducted, with one case study focusing on the the concepts of force and acceleration and the other focusing on the concepts of impulse and momentum. In each case study, pre- and post-tests were administered on two groups of students: enhanced hands-on experimentation (EHE) group and traditional textbook instruction (TTI) group. The following paragraph summaries the answer to the research question.

Research question: How effective is enhanced hands-on experimentation (EHE), compared to traditional textbook instruction (TTI), in reducing students' conceptual misunderstanding in engineering dynamics?

Answer: Through quantifying qualitative verbal data generated by 48 students with 1,248 student responses, collected through a think-aloud approach in pre- and post-tests, it was found that on the whole, enhanced hands-on experimentation is more effective than traditional textbook instruction in reducing students' conceptual misunderstanding in engineering dynamics. Among a total of eight coding categories involved in two case studies, the difference in reduction rates of students' misconception instances between EHE and TTI groups is either significant (greater than 20%) or moderate (10–19.9%) for six coding categories. It is suggested that other educational interventions be employed to supplement enhanced hands-on experimentation, in order to reduce students' incorrect understanding of high-level concepts.

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