Enriching and Enhancing Students' Learning Experiences in an Introductory Mechanical Engineering Course Through Demo Kits

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Abstract
Mechanical Engineering for Modern Life is an introductory course designed for Year-1 undergraduate students, aiming to provide them with a comprehensive overview of the field of mechanical engineering and its sub-areas. To bridge the knowledge gap between Year 1 students and the theoretical concepts in different sub-areas of mechanical engineering, we have utilized a series of demonstration kits as visual aids for various theoretical concepts. For instance, we have used model aircraft lift demonstrator to show how lifting force is generated by an airfoil shape; we have applied a four – bar linkage demonstrator to help students understand the number of degree of freedom and visualize the Grashof's condition; we have empolyed a Venturi tube to visualize the Venturi effect and enhance understanding of Bernoulli's equation; we have utilized a mini – robotic arm to show how the manipulator is controlled to move and complete tasks. This study describes the relationship between each demo kit and the corresponding theoretical concept and focuses on analyzing the results of various surveys to evaluate the effectiveness of using the demonstration kits and quantify their impact on students' learning experiences and outcomes. The application of demonstration kits have allowed students to better grasp the theoretical concepts and enhance their performances in quizzes.

Keywords: Demonstration Kits, Learning Experiences, Effectiveness

1. Introduction

The Year-1 level Mechanical Engineering for Modern Life aims to introduce the main sub – area of Mechanical and Aerospace Engineering to prepare the students for essential understanding of this field. This course is designed with four major modules which are Module 1 - Aerospace Engineering; Module 2 - Mechanics and Materials; Module 3 - Design and Manufacturing; Module 4 - Thermofluids. According to the experiences in teaching this course over the past years, one major challenge is to balance the extent and in-depth of the topics covered with the limited theoretical knowledge that Year 1 students have about the field of mechanical engineering. We have tried different ways including using demo videos as well as online quizzes to foster students' learning. To further bridge the gap between the students' knowledge set and the theoretical concepts, promote students' engagement, and enhance their learning experiences, we have applied demonstration kits to elaborate different theoretical concepts. Demonstration kits have been used in other fields. For instance, Kim (2015) incorporated demonstrations in teaching statics course and found it helpful in engaging students in the class activities. Basheer et al. (2017) employed several electro-chemical reaction demonstrations to help junior high school students understand the oxidation and reduction concepts. Kazama (2017) built several hands-on prototypes and demonstration kits to improve students understanding in machine elements such as hydraulic and pneumatic systems. Kumkratug (2018) used portable hardware tool instead of 2D or 3D diagram to demonstrate three-phase armature winding in classroom. Rossiter et al. (2019) innovated the teaching by providing with take-home laboratory kits to enahance their hands-on experiences. Kim (2022) applied an apparatus in an introductory thermodynamics course to show energy conservation during conversion between shaft work and internal energy. Julius Fusic et al (2023) used demonstration kits in learning the three electrical machines, i.e. stepping motors. The contribution of this study lies in linking the application of demonstration kits to students' performance in quizzes.

As modern mechanical engineering is a highly interdisciplinary field and covers a wide range of sub – fields, therefore, this introductory course is divided into four modules, i.e.

(1) Module 1 – Aerospace Engineering, which includes aerodynamics; propulsion systems; gas turbine;
(2) Module 2 – Mechanics and Materials, which elaborates on statics and dynamics; solid mechanics; engineering materials such as metals and polymers;
(3) Module 3 – Design and Manufacturing, which covers control; robotics; engineering design; manufacturing; mechanisms;
(4) Module 4 – Thermo – fluids, which focuses on thermodynamics; heat transfer; fluid mechanics; energy; modern building.

The biggest challenge in providing Year – 1 undergraduate students a comprehensive overview of modern mechanical engineering lies in a good balance of breadth and depth of the chosen topics and to bridge the knowledge gap between Year 1 students and the core concepts under each topic. To tackle this problem, we utilize a series of demo kits as visual aids, through which students can well grasp the principles and enhance their understanding with better learning experiences.

2. Demonstration Kits As Visual Aids

The demonstration kits that are selected for each Module are listed in Figure 1 below.

Module 1 - Aerospace Engineering	Module 2 - Mechanics and Materials	Module 3 - Design and Manufacturing	Module 4 - Thermo-fluids
• Lift and drag force demo • Mini-scale gas turbine demo	• Force vector demo	• Mini-robotic arm demo • Four-bar linkage demo • Proximity sensor set demo	• Venturi effect demo

Figure 1. The selected demonstration kits for each Module.

Most demo kits are also small-scale experiments which were shown to students in the classroom. Students also had the opportunity of hands – on experiencing the demo kits, such as adjusting parameters and moving around different parts and to see the cause and effect. Utilizing the demonstration kits serves several purposes in the engineering course teaching and learning environment. Firstly, as an old says goes “a picture is worth a thousand words”, i.e. a demonstration kit visualizes the theoretical concepts and makes complex ideas relatively easier to understand. Seocondly, a demonstration kit greatly engages students’ attention and increase their motivation to learn. Thirdly, we hope, through the students’ active involvement with the demonstration kits, to bridge the knowledge gap between Year 1 students and the theoretical concepts.

2.1. Relationships of Demonstration Kits With Theoretical Concepts

A shown in Table 1, each demonstration kit corresponds to a theoretical concept. For instance, in Module 1 – Aerospace Engineering, a fundamental concept is how the lift and drag forces are generated on an airfoil shape. Therefore, we have choosen a demonstration kit that visually represents an object in an airfoil shape and illustrates how the object is lifted by providing an air flow. Another essential concept in this Module is how the chemical energy in a combustion is converted into mechanical energy, i.e. the thrust force generated by a jet engine and shaft rotation force produced by a gas turbine. To illustrate this concept, we utilize a mini-scale gas turbine that showcases main internal components as part of the demonstration. In Module 4 – Thermo – fluilds, Bernouli equation serves as a key principle governing flow behaviors along a streamline. The demonstration kit in this module consists of a set of glass tubes connected at some reduced cross – sections. When compressed air is introduced, the flow at different cross – sections exhibits different velocity and different pressure. This difference in pressure is visualized by the varying height of liquid in the glass tube accordingly.

Table 1. Matching of Each Demonstration Kit With the Topic and Theoretical Concept

Demonstration kits	Matching topic and theoretical concepts
Lift and drag force demo	• 3D shape of an anfoil object; • how lift and drag forces are generated;
Mini-scale gas turbine demo	• how a gas turbine works;
Force vector demo	• how a force triangle is formed by three concurrent forces acting on an object;
Mini – robotic arm demo	• number of degree of freedom of a joint; • how the robotic arm is manipulated;
Four – bar linkage demo	• number of degree of freedom of a linkage; • shapes that a linkage can trace;
Proximity sensor set demo	• how the position of an object is sensed by optical and magnetic means;
Venturi effect demo	• how pressure and flow velocity change with each other in the Bernoulli equation.

2.2. Results and Discussion

In order to evaluate the effectiveness of utilizing various demonstration kits in this course, we launched a survey after students have completed learning in Module 1 and received feedback with a response rate of 34%. Both the survey questions and the scoring scheme are listed in the following Table 2.

Table 2. Survey Questions for Module 1

Survey questions for Module 1	Score range	Average score
1. *Both Lift and Drage Force demo and MIni-Scale Gas Turbine demo are relevant to Aerodynamics chapter.*	Min. 1 (Strongly disagree); 3 (Neutral); Max 5 (Strongly agree)	4.26
2. *The Life and Drag Force demo visualizes Airfoil and helps me understand how lift and drag forces are generated in Aerodynamics.*	Min. 1 (Strongly disagree); 3 (Neutral); Max 5 (Strongly agree)	3.92
3. *The Mini-Scale Gas Turbine demo visualizes the internal structure of the gas turbine and helps me understand the general working principle of a gas turbine.*	Min. 1 (Strongly disagree); 3 (Neutral); Max 5 (Strongly agree)	3.68
4. *Please help QUANTIFY the difference (if any) in your learning experiences between with the demo kits and without the demo kits.*	Min. 1 (Negative effect – better without demo kit); Max 5 (Significantly better with demo kit)	3.39
5. *This demo kits have helped me to conduct related quizzes and assignment.*	Min. 1 (Strongly disagree); 3 (Neutral); Max 5 (Strongly agree)	3.39
6. *The online quizzes support me further understand the concepts learned in lectures.*	Min. 1 (Strongly disagree); 3 (Neutral); Max 5 (Strongly agree)	3.92

Source: Internal Survey Data (with a response rate of 34%)

The average scores for each survey question is also presented in Figure 2 below. Question 1 has received the highest average score, indicating that most students perceive both demonstration kits – Lift and drag force and Mini-scale gas turbine – as highly relevant to the core concepts in Aerohyanmics. Question 2 has obtained the second highest score, suggesting that many students have found the two demonstration kits helpul in understanding the concept of lift and drag force on an airfol. On the other hand, Question 4 and 5 have received the lowest score, indicating that students feel the impact of demonstration kits is only slightly better than learning without them. Furthermore, the effect of demonstration kits on conducting quizzes and assignments is considered marginal.

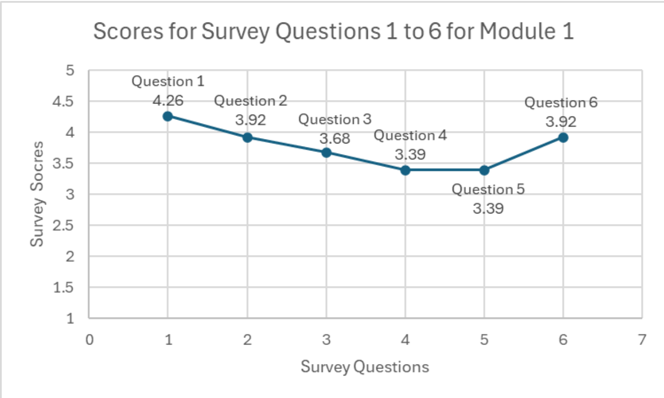

Figure 2. The Average Survey Scores for Survey Question 1 Through 6 for Module 1.

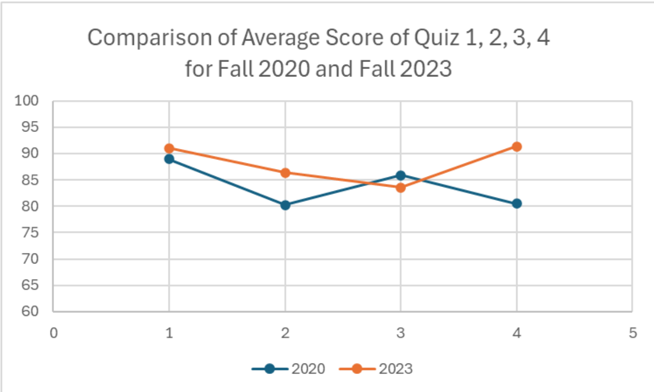

Figure 3. Comparison of Average Score of Quiz 1, 2, 3, 4 for Fall 2020 (Without Demo) and Fall 2023 (With Demo).

In this course, we incorporate an online quiz following each module as part of assessing students' learning outcomes. To further evaluate the impact of utilizing demonstration kits on the administration of online quizzes, we have compared the average scores for the same set of four online quizzes from the year 2020 (without demonstration kits) and 2023 (with demonstration kits), respectively. The results indicate a slightly improved average score of 91.01 in 2023 than 88.91 in 2020 for Module 1. For Module 3, the average score without demo in 2020 is even slightly better than that with demo in 2023. We will re-evaluate the choice of demo for Module 3 in future semesters. On the other had, there is a significant increase in the average score in Module 2 and 4. Unfortunately, due to time onstraints, we are not able to conduct surveys for other Modules. We plan to conduct surveys in Module 2 and 4 in future semesters.

2.3. Additional Comments From Students

In addition to survey questions with scores, we also include an open – ended question in the survey, so that students can express their views with wider aspects of evaluation. Some comments are cited in Table 3 below.

Table 3. Open-Ended Comments From Students

Do you have any other comments about Module 1?
Some comments for question 7: • Overall, I thought it was great. Good introduction to the world of aeronautics and astronautics. There are good pauses where we are encouraged to calculate the answers using the formula we have just learned. This is very helpful in reinforcing not only how to use the formula, but what it means. Thank you • The lectures, powerpoints and demo kits are very detailed, clear and useful for my understanding of concepts of topics in Module 1. • If the lift and drag demo kit can come with smoke to show the air streamline and the gas turbine is driven by the energy from combustion that seems will be better. • the propeller airfoil, downwash, vortices, induced drag concepts are quite difficult to understand. • I would've preferred if the demo kits were projected onto the big screens and explained more clearly, maybe with annotations.

Source: Internal Survey Data

Students have provided generally positive feedbacks and constructive advice to us. The suggestion in the last comment has been taken and implemented in the demonstration in Module 2, 3, and 4.

3. Conclusions

A total of seven demonstration kits have been carefully selected across the four learning modules, such that each of them visually support a fundamental concept for a specific topic. Survey questions for Module 1 are constructed to investigate students' learning experiences from various perspectives. The internal survey results indicate that students' general perception about the demonstration kits in Module 1 is positive, therefore, we will keep them as key components in this course.. Some average scores are lower than the other, which serves as a guideline for adjustment of demo kits selections in future semesters. The suggestions in the open-ended questions will further help us fine tune the selection of demonstration kits and further better structure them as an effective learning aid. The average scores in online quizzes with and without demonstration kits further confirms that demonstration kits are generally helpful in improving students' performance.

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