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# A Lab Introducing the Components of a Mechatronic System

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# A Lab Introducing the Components of a Mechatronic System


## Abstract

*In engineering courses involving experimentation, students are exposed to a standard actuator (such as stepper motor or servo motor) with a motor driver, a microcontroller board (say an Arduino Uno) and sensors (such as an inertial measurement unit and an ultrasonic sensor). These components can directly interface with the microcontroller board and are made operational through a straightforward program and circuitry. But a typical mechatronic system consists of several components and it is important to introduce those to students to make them industry ready. Therefore, this paper explains a laboratory exercise implemented in a senior level design and modeling course at Worcester Polytechnic Institute (WPI) that introduces various components typically used in a mechatronic system. The system that was selected for this purpose was an eddy current brake testing machine that was developed for a research project consisting of different actuators, sensors, relays, motor drivers and so on. Detailed instruction guides were presented to the students explaining the activities that have to be carried out. The activity was implemented in multiple iterations of this course and subjected to various forms of improvements through informal student feedback. Formal student feedback was collected during Fall 2025, which showed that the laboratory exercise met the desired learning objectives. The paper will discuss the implementation details along with student feedback and observations from the teaching team.*



Keywords: mechatronic system; components; laboratory; sensors; senior-level curriculum


## Introduction

A mechatronic system consists of four major components namely mechanism, actuator, sensor and control algorithm [1] (Note: actuators and sensors may be classified as one or sensor and control algorithm may be classified as one depending on the literature). A mechanism can be a linkage, gear-train or cam-follower system while an actuator can be one of several types of rotary motors or a linear actuator. There are several types of sensors such as a hall-effect sensor, encoder, inertial measurement unit (IMU), etc. that can be integrated into a system. The data from the sensors are collected, analyzed and used in a control algorithm that will be used to actuate the input to the mechanism. In addition to these standard components, there are a lot of electrical and electronic components including microcontrollers, motor drivers, relays and others that are used in conjunction with the four components to realize a mechatronic system.

A review of literature showcases various types of laboratory experiments pertaining to mechatronic systems particularly involving dynamics, controls and sensors. Sabuncu and Sullivan [2] talk about an online experimentation course using Arduino and Raspberry Pi and different sensors and actuators. Chinwong et al.[3] also utilize a simpler Arduino-based system along with a virtual environment called TinkerCAD [4] to expose various physics and mechanical concepts to computer engineering students. Anuchin et al. [5] focuses on test benches for electric drives for electrical engineering students. While these are promising activities that could potentially be emulated, they are either too simple (such as [2],[3]) or focus on a single area such as electrical engineering rather than a holistic mechatronic system. A machine that combines elements of [2],[3] and [5] would be ideal for the laboratory exercise that was being considered.

Before designing or selecting a machine for this lab activity, three learning objectives were formalized. The first objective was to introduce all possible components used in a mechatronic system. The second objective was to get students to explore the uses of these components through a web or literature search along with obtaining and understanding relevant specifications. The third objective was to get students to use handheld measurement systems and a serial monitor to obtain performance data from the machine. Based on these objectives, different machines were explored. Two different machines were under consideration. One was a four-bar linkage (shown in Figure 1) and the second was an eddy current braking machine (shown in Figure 2). The four-bar linkage machine utilized an actuator, sensors and controller but had the same issue as seen in the literature that it was rather simple and did not meet our first learning objective. The eddy current machine met all three objectives since there were multiple actuators, sensors and a complete suite of electrical and electronics components since this was designed and prototyped for a research project.

The laboratory activity was integrated into the mechanical and robotics engineering course, *Modeling and Analysis of Mechatronic Systems* at WPI. The course discussed different mechatronic systems and this lab was essential to provide a good introduction to students. Each student in the course worked with the machine, understood various components and carried out data collection as prescribed in the lab handout. A report was also written summarizing their findings. During Fall 2025, a survey was conducted to ascertain if such laboratory exercises provided value and met the learning objectives.

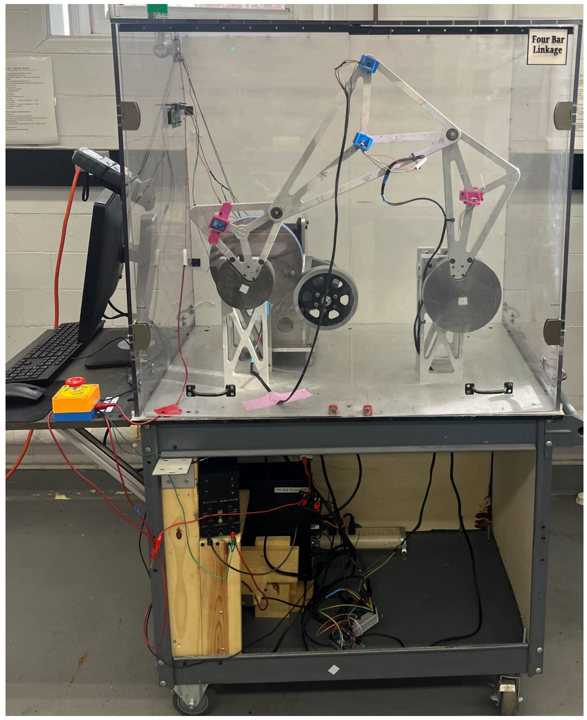



*Figure 1: Four-bar Linkage that was considered for the laboratory activity*

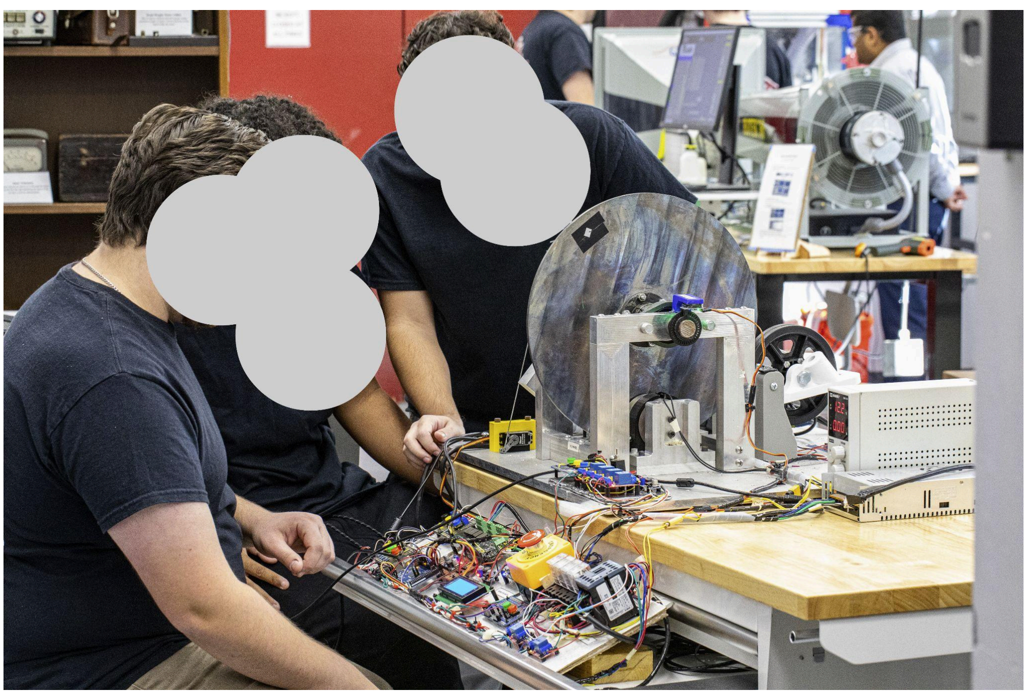


*Figure 2: Students Working on the Eddy Current Braking Machine*

The paper is organized as follows. Section 2 describes the equipment, experiment, expectations of the laboratory and the survey design. This will be followed by discussion of the survey results, teaching team's insights and a discussion on the next steps in Section 3. Section 4 will provide conclusions and future steps followed by listing of sample work and laboratory handouts as appendices.

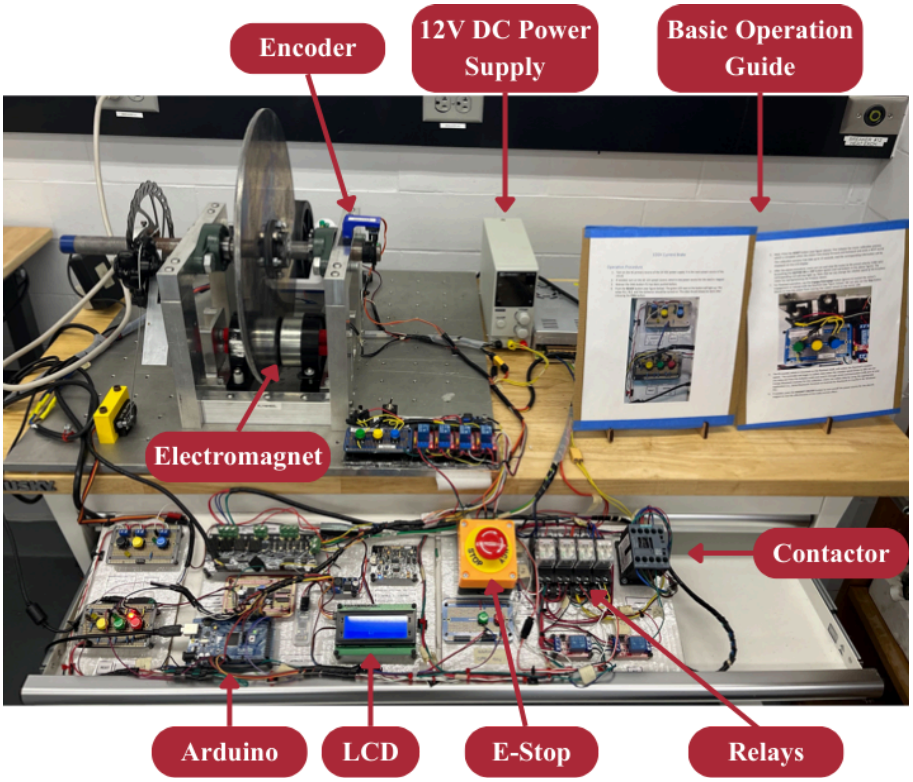
## 2. Methods

This section will describe the equipment details followed by the laboratory activity, reporting expectation and survey design to capture student thoughts.

### 2.1 Equipment and Instrumentation

The laboratory utilizes a mechanical assembly consisting of a friction wheel, flywheel, electromagnet, and various sensors and electrical components (shown in Figure 3). The system was developed for a research project in 2021 that explored the effectiveness of eddy current braking using different electromagnets [6]. For use in the course, it was fitted with an ODrive motor [7] and linear actuator [8] to incorporate a retractable friction wheel in 2023. The eddy current braking mechanism flywheel can reach speeds of up to 500 RPM before the flywheel disengages. For safety purposes, a disc brake is fitted around the flywheel that engages when an emergency stop is pushed.

To capture speed data, the assembly includes a custom hall-effect encoder capable of tracking revolutions per minute through the use of magnets [9]. All sensor data is processed via an Arduino microcontroller [10] and captured through a serial monitor for post-processing.



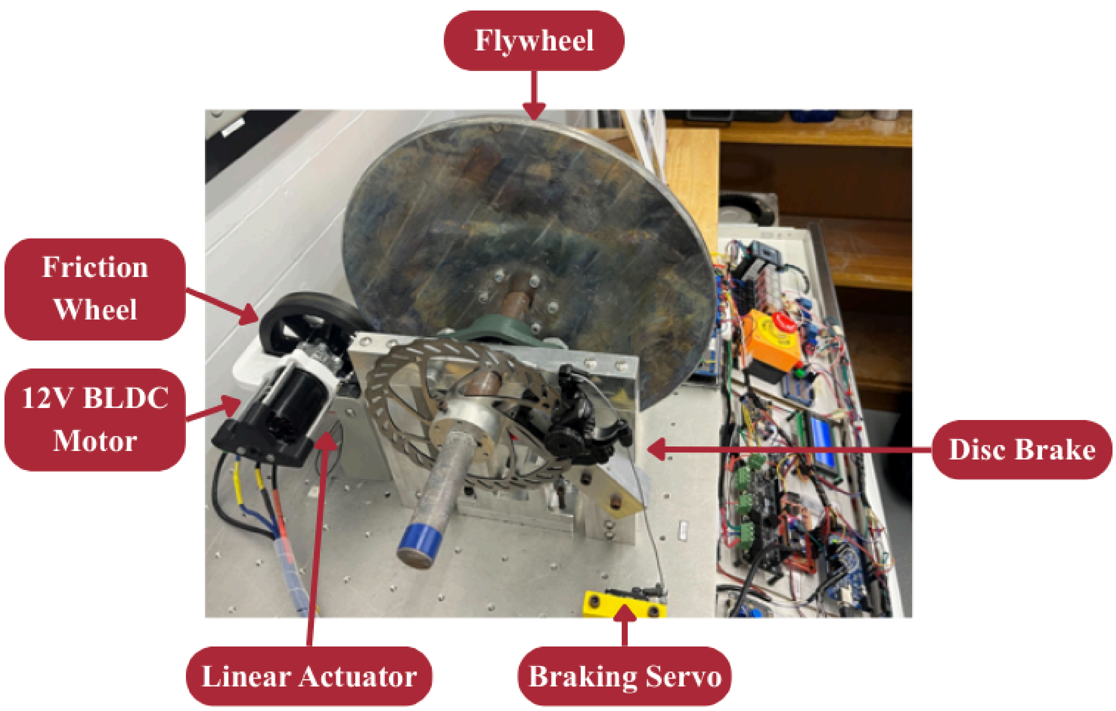




*Figure 3: (top) Eddy Current Brake Mechanism with Important Components; (bottom) Perspective view of the Eddy Current Brake Mechanism with Important Components*

### 2.2 Experiment and Laboratory Setup

The laboratory is structured as an out-of-class activity facilitated by the teaching assistant. To ensure preparation and safety, students are provided with a lab handout (linked in the appendix). Students arrive at the laboratory equipped with safety glasses, close-toed shoes, and pants. They proceed to operate the eddy current machine. There are two phases to this activity namely Data Collection and Data Processing as shown in the process flow in Figures 4 and 5.

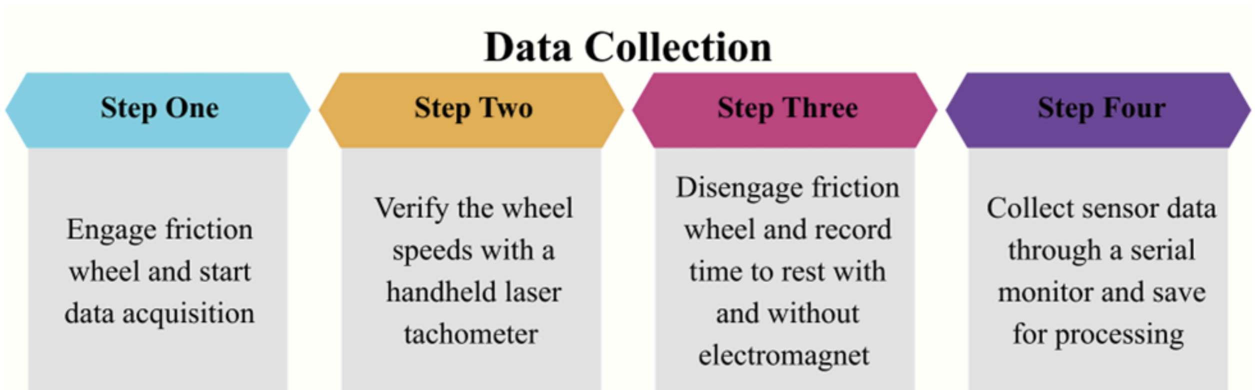


*Figure 4: Data Collection Flowchart*

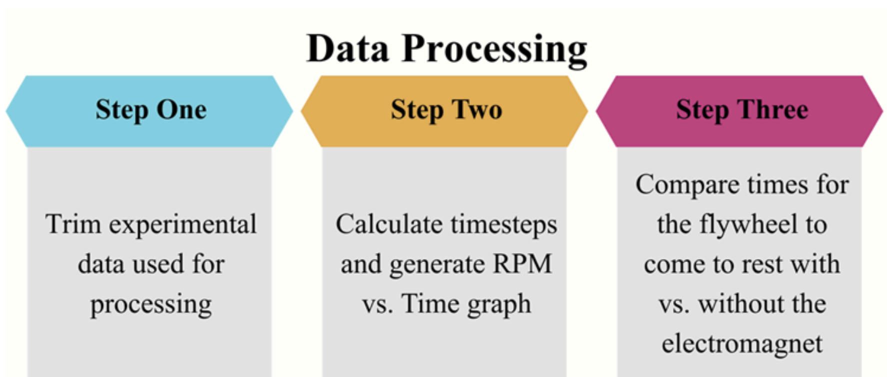


*Figure 5: Data Processing Flowchart*

To begin the experiment, students power the machine on and engage the friction wheel, allowing the sensors to autocalibrate. Once the motor initiates the friction wheel's rotation, the linear actuator moves the friction wheel to the flywheel, allowing the flywheel to start rotating. Students then use a handheld laser tachometer to verify that the speeds of both the friction wheel and the flywheel align with the encoder readings. After confirmation, the friction wheel is disengaged, and students use a stopwatch to measure the time required for the flywheel to come to a complete rest. This process is conducted across two trials: the first involves allowing the flywheel to decelerate naturally, while the second requires engaging the electromagnet immediately after the friction wheel is disengaged. Data from both trials is recorded for post-processing. Finally, the lab concludes with students measuring the air gap between the electromagnet and the flywheel using dial or vernier calipers.

The second part of the lab activity involves the data processing and report writing phases. Data processing involves adjusting the timestep based on stopwatch recordings and plotting the speed over time recorded in each trial. This data is then tabulated and the times to come to rest in both trials are compared. These steps are explained in the process flow shown in Figure 5.

Students are given the option to write the report either individually or as a group. The report involves summarizing the experimental setup, results of data processing as well as inferences from data processing and general learning observations.  This is detailed in Section 2.4

**2.3 Experiment Results**

After post-processing, students use the speed (RPM) vs. time graph to highlight the differences between their two trials. By comparing the experimental data, the eddy current braking effectiveness can be validated. Shown in Figure 6 is an example of a typical graph students used to compare data and extract inferences. As indicated in the figure, the flywheel comes to a stop in around 35-40 seconds with eddy current braking compared to 110 seconds without eddy current braking.

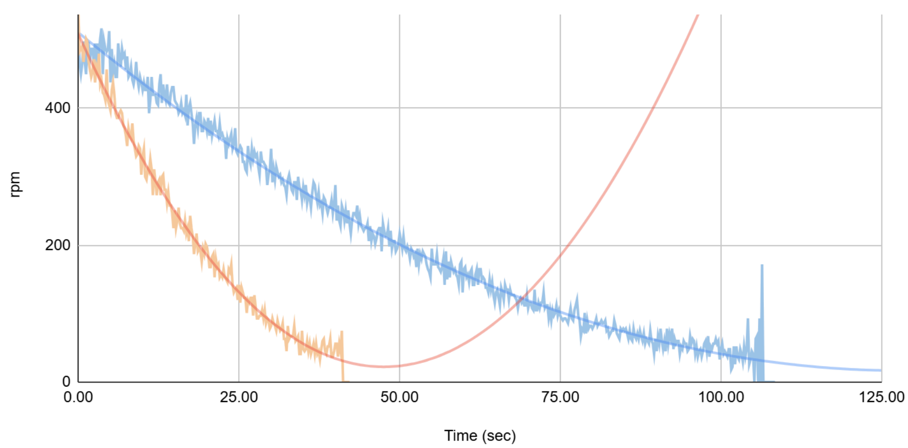



*Figure 6: Example of  Student Processed Data*

**2.4 Lab Report and Submission Requirements**

The primary deliverable for this experiment is a formal technical lab report. Within this document, students must detail the  technical specifications of the equipment and the specific processes followed during the lab. A critical component of the report is the tabulation of the times it took the flywheel to come to rest in each trial. Students are expected to discuss whether the eddy current braking mechanism has value in other applications, and how the lab enhanced their understanding of what comprises a mechatronic system. Sample lab reports are linked in the appendix.

## 3. Results and Discussion

This section details insights gained on the class performance, results of the survey, thoughts of the teaching team as well as a discussion on the learning objectives.

### 3.1 Student Performance and Teaching Team’s Observations

Twenty-five students carried out this experiment during Fall 2025 and responded in an anonymous survey out of 32 students. A majority successfully carried out data collection and data processing independently.

The average class score in this laboratory was 85.5%. The most significant impact on student grades occurred in the System Information section where students lost an average of 10.3 points out of the 50 available (a 20.7% loss). Deductions in this area were primarily due to a lack of technical detail regarding various hardware components. Many reports were missing call-out arrows to identify specific sensors and actuators in figures, and several failed to provide actual specifications.

While the System Information section was a large contributor to point deductions, the References category saw the highest proportional loss, with students losing 27.4% of the possible points. The majority of these losses stemmed from students failing to include in-text citations or neglecting to provide references for the underlying physics concepts, such as Lenz's Law and eddy currents.

Other notable deductions were found in the Discussion and Introduction sections, which saw average losses of 13.6% and 11.9%, respectively. In the Introduction, points were frequently lost for failing to explain Lenz's Law or the associated braking phenomenon in sufficient detail. In the Discussion section, students often struggled to articulate how the experiment specifically deepened their understanding of mechatronic system integration. In the Processed Data section, which accounted for an 11.3% loss, the most common error was the failure to tabulate and compare results between different team members, especially when differences in braking times were observed.

### 3.2 Survey Results

To establish a baseline for the student's prior knowledge, the survey first assessed familiarity with the core concepts of the lab as shown in Figure 7. Results indicated that a majority of the cohort entered the laboratory with limited knowledge of Lenz's Law and Eddy Currents [11]. Specifically, 64% of students reported having no prior understanding of Lenz's Law and Eddy Currents. However, 76% of students were familiar with microcontrollers such as Arduino prior to the lab.

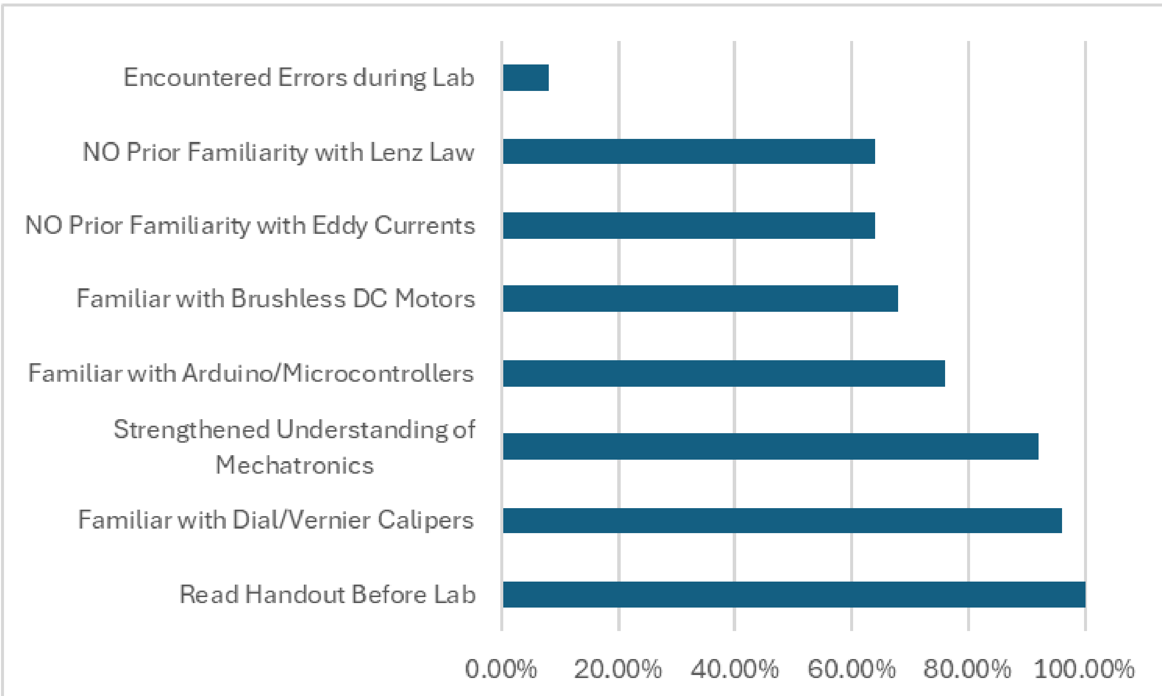



*Figure 7: Prior Experience and Background Knowledge of Students*

Instructional materials such as the experiment handout, were generally well-received with a mean score of 4.04, and students found the teaching team's assistance during the data processing phase helpful with a mean score of 4.28. While the development of report writing and conclusion-drawing skills received a slightly lower mean of 3.68, the overall survey results indicate that Lab 1 served as an effective and accessible introduction to the course, bridging the gap between theoretical physics and mechatronics. These results are consolidated in Figure 8.

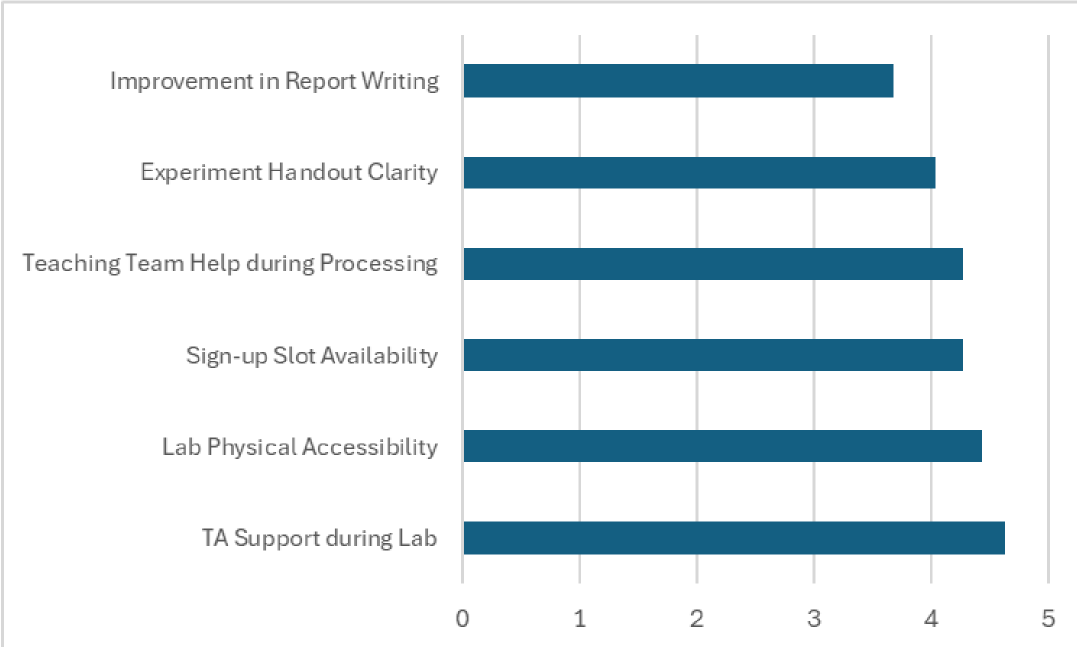



*Figure 8: The Average Response of Survey Questions Ranked 1-5, with 1 Indicating a Need for Improvement and 5 Indicating Satisfaction*

**3.3 Discussion**

Students are exposed to various components of a mechatronic system in different courses during their engineering degree. The difference between those systems and activities to the one explained in this paper is the complexity as well as near completeness of the system itself. While commercial systems are available, they do not lend themselves well to the first learning objective (introducing various components of a mechatronic system) since most of them are closed source systems. In the eddy current braking machine described in this paper (in Section 2), all elements of a complex mechatronic system are available but in such a way that students can actually see and understand their uses. Students also realized that there are more than a few components required for successful, repeatable and robust working of a mechatronic system. This was very important for the teaching team since the first learning objective is essentially geared towards making students industry-ready.

This laboratory was also a good introductory activity for students since they would have researched specifications of different components, used vernier calipers and tachometers, extracted data from a serial monitor as well as written a report summarizing their activities. All these were essential building blocks for advanced labs in the same course.

While there are ample positives in this laboratory activity, there are some negatives in this approach. One is scalability. Due to the nature of the machine and the components used, this type of machine may not be miniaturized or even replicated. Miniaturization is challenging since that would essentially mean stripping down on components while replicating this machine means significant investment. But if there are similar machines or commercial machines that are not utilized, those can potentially be repurposed for developing a laboratory exercise described in this paper. The other negative is the significant time commitment to complete a physical experiment individually. Students are allocated as much as 45 minutes for this laboratory. This would work for smaller class sizes but in larger sections, individual activity may not be feasible and group work may be required.

### 3.4 Future Work

The Eddy Current Brake is expected to be redesigned before the 2026-2027 academic year to improve student learning outcomes and safety. Enhanced safety features such as a protective shielding around the flywheel, a treelight indicating operational status, and a more durable servo-motor to stop the flywheel when the emergency stop is pressed will be integrated. Furthermore, wiring and callout labels on system components will be redone to ensure students can correctly identify sensors and understand how the system functions upon observation.

## 4. Conclusion:

The paper describes a laboratory exercise that introduces students to various components of a mechatronic system. An eddy current braking machine, developed for a research project, consisting of several mechanisms, actuators, sensors and electronics was used. Students learn about various components, research their specifications and in the process get to experience the effectiveness of eddy current braking along with utilizing hand-held measuring tools like vernier caliper and tachometer. Results of the survey shared with students points to the fact that the learning objectives were well received while at the same time, pointing to more guidance being needed during the reporting phases of the laboratory activity.

## 5. Acknowledgements:

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**Appendices:**

Lab Handout: Link
Sample Student Submission: Example 1 | Example 2
Anonymized Survey Result: Link