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# Design and Implementation of an AI Chatbot for a Mechanical Engineering Undergraduate Laboratory Course

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# Design and Implementation of an AI Chatbot for a Mechanical Engineering Undergraduate Laboratory Course

**Abstract:** The enrollment growth in undergraduate mechanical engineering programs can be attributed to interest in STEM careers driven by emerging technologies and government-society promotion efforts. At Clemson University, the undergraduate laboratories' three-course sequence provides critical experiential learning opportunities. As the demand for laboratory sections increases, additional trained graduate laboratory assistants (GLAs) are needed to instruct, supervise, grade, and ensure that safety protocols are followed. There is a need to supplement the resources available to students before, during, and after the laboratory experiment to answer questions ranging from simple to complex. The emergence of AI Chatbots, based on natural language processing and machine learning, can respond to student questions 24/7. In this paper, a Chatbot will be created, trained, and deployed to support GLAs in answering student questions for laboratory experiments. A pilot study has been conducted to explore its general utility and potential in a sophomore-level ME 2220 (Mechanical Engineering Laboratory I) course with student survey results and instructor observations. Specifically, the research objective is to assess the potential for AI chatbots to improve student outcomes, improve student engagement with modern tools, and increase student satisfaction. AI chatbots have been known to provide misleading or inaccurate information in some instances, so an important outcome of the project is to validate the chatbot for accuracy specific to the outcomes for the laboratory modules as much as possible and to identify strategies to implement tools that are known to have inaccuracies. The laboratory course introduces fundamental principles of precision, accuracy, and uncertainty associated with measurement instruments, making it a suitable location in the curriculum to introduce students to using AI Chatbots as an assistive tool to improve student learning.

## 1. Introduction

Artificial intelligence (AI) chatbots are software systems that communicate with users through natural language. Traditional chatbots operate using predefined rules and scripts exclusively, in contrast to AI chatbots that integrate machine learning and natural language processing to understand and generate responses probabilistically. These systems have the potential to enhance student learning, support instructional scalability to increase lab class size, and improve access to timely feedback across multiple phases of the engineering laboratory experience. Through carefully developed conversational instructions, chatbots can guide students through learning objectives, fundamental theory, experimental procedures, and safety considerations before they enter the laboratory. At their best, they permit students to engage with content at their own pace, receive immediate formative feedback, and arrive better prepared for in-person lab activities. AI chatbots can also function as virtual teammates during the lab that supplement human instructional support. The chatbot can clarify procedural steps, answer common conceptual questions, and prompt students to reflect on unexpected results while the instructor circulates throughout the laboratory room. After the scheduled lab period, an AI chatbot can serve as a continuously available resource for students supporting their completion of data analysis and laboratory report writing. It can be accessible all hours of the day to answer clarifying questions, help scaffold analytical reasoning, and reinforce best practices in engineering communication. The role of a chatbot within a laboratory course has been illustrated in Fig. 1.

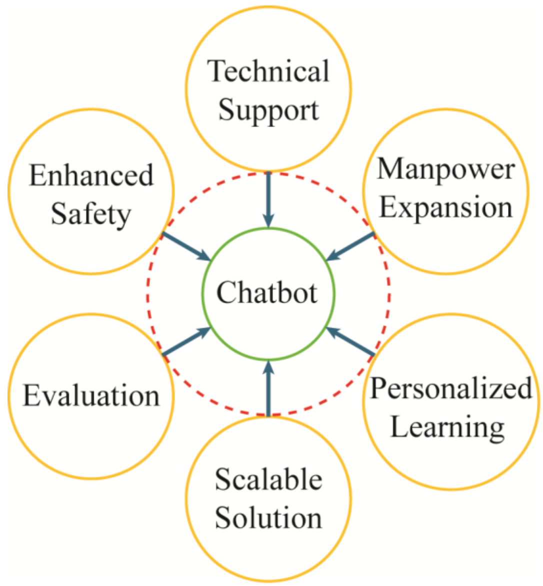


Fig. 1. Role of Chatbots in higher education laboratory learning.

AI chatbots can strengthen academic learning, as reported by Yassine et al. [1], Jack and Yan [2], and Sanchez-Soto et al. [3], in terms of critical thinking and concept understanding. Sharipova et al. [4] examined specifically the impact within mechanical engineering education. The reader is referred to [5-6] for more general information concerning chatbots. Despite these potential benefits, the implementation of AI chatbots in higher education presents significant challenges. The obvious concern is that students could use such tools to generate content and circumvent the learning process, rather than use it as an assistive tool to enhance their understanding. Additionally, AI chatbots can be inaccurate, providing incorrect explanations, misleading reasoning, or oversimplified responses to complex engineering problems. In a laboratory context, such errors can be especially problematic if students rely on them uncritically. Cost and access disparities, created by licensing fees, and usage-based billing structures, may disproportionately affect students or departments with limited resources. Data privacy and security also warrant careful consideration. Ensuring compliance with institutional standards is important to successful implementation. Concerns related to bias and discrimination further complicate adoption, as AI systems may reflect or amplify social and cultural biases, potentially creating unequal opportunities. These limitations underscore the importance of framing AI chatbots as supplemental tools rather than authoritative sources of truth.

Prior research emphasizes the importance of compliance with institutional information technology (IT) policies and of allocating ample time to collaborate with IT offices during planning and deployment. During AI chatbot development, careful consideration of billing structures and financial impacts to students and academic units, alongside deliberate restrictions on training materials to prevent unintended data exposure, supports a framework to increase the likelihood of enhanced student learning and improved student experience in engineering laboratory education [7].

The development, introduction, and assessment of a Chatbot in a sophomore-level undergraduate mechanical engineering laboratory course to assist in the learning process will be investigated to evaluate the effectiveness of this emerging AI technology. The research team has pursued this study to better understand the benefits and challenges in supporting the growing undergraduate laboratory enrollment through chatbot assistance. Measures of this include: comparisons between the pilot sections and control sections of student performance on lab reports (i.e. scores), and comparisons of student perception from surveys administered to the pilot sections and control sections after completion of the module, and instructor observations of use during class. The remainder of the paper has been organized as follows. Section 2 introduces Chatbots and provides a concise technology overview. In Section 3, the undergraduate laboratory program at Clemson University is reviewed to help motivate the investigation. The case study with assessment data is presented in Section 4 after the application for the first experiment in the sophomore laboratory course. Finally, Section 5 contains the Conclusion followed by the References.

## 2. Chatbot Primer and Architecture

By characterizing the chatbot as a learning assistance tool rather than a solution generator, the primer promotes academic integrity and ethical use of the chatbot. It does not produce a comprehensive lab report for the student to turn in or offer a direct response to the graded assignments. Rather, the chatbot is intended to help students gain a basic grasp of lab modules, both during and outside of the lab schedule when the course instructor or teaching assistant is not accessible. Clarifying instructor expectations for appropriate AI use and discouraging misuse are two benefits of communicating these limitations up front. The increasing use of generative AI tools in academic workflows makes it especially crucial.

In addition, the primer guides students toward effective interaction strategies. Students are encouraged to use targeted, context-rich prompts by specifying the laboratory modules, the relevant experimental step or concept, the nature of the difficulty encountered, and the intended learning objective. For example, prompts such as “Can you explain how uncertainties for PDT are calculated in this experiment?” or “What does sensitivity indicate about UDS behavior?” promote more relevant and informative responses. This structured approach improves both the quality of chatbot outputs, the efficiency of student–chatbot interactions, and trains students to effectively use these modern tools for other applications.

Given the experimental nature of laboratory-based courses, the primer also highlights system limitations and safety considerations. Students are reminded that chatbot responses may occasionally be incomplete or inaccurate and that all critical experimental decisions should be verified using official laboratory manuals, instructor guidance, and safety documentation. For issues related to equipment operation, safety, or experimental validity, students are explicitly instructed to consult a teaching assistant or instructor.

From a system perspective, the chatbot primer functions as part of the user experience and control layer of the overall chatbot architecture. While Copilot Studio manages backend behavior, access control, and response constraints, the primer provides a clear, human-readable interface that aligns user expectations with system capabilities. Implemented as both an introductory message and a persistent reference within the Canvas-integrated Microsoft 365 Copilot environment, this combined approach supports consistent, transparent, and policy-compliant chatbot usage.

Fig. 2 presents the system architecture of the proposed educational chatbot developed for the Calibration laboratory module within the Clemson University digital learning environment. Students access the chatbot through the Canvas learning management system (LMS) using their institutional credentials, ensuring that interaction is limited to authorized and enrolled users. Microsoft 365 Copilot manages authentication and session handling, serving as a secure integration layer between Canvas and the chatbot backend.

Once authenticated, student queries are routed to a Copilot Studio–based agent, where the conversational logic is implemented under institutional data security and privacy controls. The chatbot operates as a closed-domain system, with external web search disabled, and relies exclusively on curated course materials, including laboratory manuals, lecture slides, experimental video transcripts, report structure templates, and formatting guidelines. This design ensures that responses remain grounded in official instructional resources and aligned with course objectives. In other words, the response to students is focused on data provided to Copilot by instructors.

An instruction and compliance layer within Copilot Studio governs intent recognition, prompt orchestration, and rule-based constraints. Acting as a policy gate, this layer limits the chatbot from providing direct answers to graded assessments or generating complete laboratory reports, while encouraging conceptual understanding, procedural guidance, and analytical reasoning. For example, a student entering a prompt to “write my lab report”, or something similar, will receive a message recommending how to use the chatbot for learning not report generation. Interaction logging and analytics are integrated to capture usage patterns and common student queries, supporting ongoing evaluation and refinement of the system.

To address the practical and safety-critical nature of laboratory instruction, the architecture includes a human escalation pathway. When questions involve equipment operation, safety concerns, or experimental validity, the chatbot directs students to consult a teaching assistant or instructor. Responses are returned through Microsoft 365 Copilot and displayed within Canvas, completing a secure, consistent, and pedagogically responsible interaction loop.

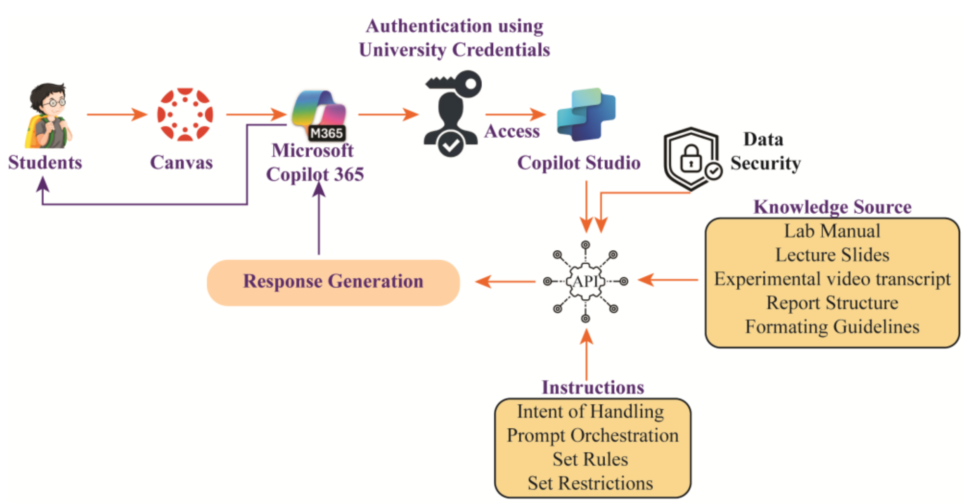


Fig. 2. Chatbot architecture for integration into an academic course

## 3. Target Mechanical Engineering Laboratory Course

The Clemson University Department of Mechanical Engineering has an undergraduate student population of approximately 1,200 for the 2025-2026 academic year. An annual enrollment rate of 4% has been experienced over the last five years, reflecting both the regional industrial demand for engineers and the broad utility of the degree. The BSME curriculum requires 127 credit hours to graduate, with the option to participate in cooperative education (co-op) programs with companies to gain workplace career training. A strength of the mechanical engineering program is the required three-course laboratory sequence, which is completed during the sophomore, junior, and senior years. These courses are standalone, focusing on the discovery of mechanical engineering principles and phenomena, as well as student-conducted experiments, instrumentation, calibration, data acquisition, analysis, and report writing. The benchtop experiments encompass a range of activities, including material testing, CNC and manual machining, thermal fluid system energy balancing, vibration analysis, coding of programmable logic controllers, mechanical systems analysis, and sensor testing. To deliver these two credit-hour courses, graduate laboratory assistants (GLAs) are present in the classroom for six hours each week during the semester per section, and a section will contain 16-20 students. From a manpower perspective, the required number of GLAs is directly proportional to the student enrollment, which may become challenging.

The laboratory instruction model features online materials that the students are required to review prior to the actual laboratory commencing. These learning materials typically consist of a combination of lab manual notes, videos of GLAs conducting the actual experiment, and knowledge assessment quizzes. The manual provides a comprehensive description of the experiment and detailed instructions for the safe completion of the laboratory work. In some instances, students are expected to determine the experimental approach, so the instructions are limited and the end deliverables emphasized. In the classroom, the GLA will emphasize the underlying engineering principles and corresponding theoretical equations. Once the students engage with the equipment, the GLAs help to ensure a safe environment and answer questions such as "Why does my experiment not work?" or "Why are the results different than the theory?" Once the experiment has been concluded, the data analysis and report writing tasks are completed under the guidance of the GLA. To help prepare the graduate students to serve as laboratory assistants, extensive training occurs before and during the semester, with a core of experienced graduate students available to help train and mentor the new students joining the ME 2220-3330-4440 teams.

To help alleviate the in-class demand on GLAs and enhance the *a priori*/*a posteriori* experiences of the students, the introduction of a Chatbot is proposed. Common questions concerning a particular experiment's testing steps, data collection techniques, and data analysis methods can likely be answered using a machine learning/artificial intelligence tool. In other words, the low-level inquiries to GLAs may be routinely answered by the Chatbot, thereby improving the overall efficiency and effectiveness of the GLA. More importantly, the students will have timely responses to their questions, which could accelerate the learning process.

## 4. Pilot Study

The pilot study was conducted for two weeks during the Spring 2026 semester in the sophomore-level required mechanical engineering laboratory course. Two sections, out of fourteen, with 20 students enrolled in each, were selected. The students in these pilot sections were provided with an introductory set of instructions and then given the option to use the AI Chatbot for the experiment. In this section, the laboratory course, Chatbot design, and observations will be presented to fully highlight the target application and initial findings.

### 4.1 Sophomore Level ME 2220

The 2-credit hour sophomore laboratory course is offered during the fall and spring semesters to both mechanical engineering students, and as a service course to automotive engineering students. The course features experiential learning and technical writing as noted in the catalog description.

> *"Discovery of mechanical engineering principles and phenomena. Introduction to laboratory safety practices, instrumentation, calibration techniques, data analysis, and report writing. Introduction to basic manufacturing processes. Preq:* ***PHYS 1220*** *and* ***PHYS 1240*** *and* ***MATH 1080****, each with a C or better."*

The laboratory curriculum includes calibration (potentiometric displacement transducer, ultrasonic distance sensor), Arduino microcontroller programming, Industrial Safety with hands on application to hand tools, drill press, lathes, and vertical mills. In addition to a Programmable Logic Controller (PLC) with a human-machine interface (HMI), material properties were explored through stress and strain testing of metal and fiber-reinforced composite samples. Next, fluid mechanics is investigated with flow loops and blower systems, followed by the reverse engineering of a small internal combustion engine.

For this study, the multi-week Calibration Experiment has been selected, in which students learn to calibrate two displacement transducers: a potentiometric displacement transducer (PDT) and an ultrasonic distance sensor. They learn how to interpret basic circuit diagrams, assemble electronic circuits, discuss range and sensitivity, and perform linear regression analysis.

### 4.2 Chatbot Design and Implementation

The chatbot was implemented as a pilot deployment for the Calibration module in the sophomore-level ME 2220 laboratory course. The chatbot was developed to address common student questions about the equipment operation, calibration procedures, data analysis, and report preparation, while deliberately excluding direct answers to graded assessments. Course-specific instructional materials, including the laboratory manual, lecture slides, transcript of experimental videos, and report templates, were curated, reviewed by the instructional team, and organized prior to creating the chatbot knowledge base to ensure alignment with course objectives and laboratory safety expectations.

Implementation was carried out using Microsoft Copilot Studio, where the chatbot was configured to provide controlled, instructional responses grounded in the approved course materials. A combination of structured topic flows and generative responses was employed to support conceptual clarification and procedural guidance. Configuration rules were applied to enforce refusal behavior for requests related to graded assignments and to maintain a consistent instructional tone and response length. As illustrated in Fig. 5, the chatbot provides concise explanations to common conceptual questions (e.g., the significance of sensor sensitivity) and procedural inquiries while avoiding step-by-step solutions or complete report-ready outputs.

The chatbot was deployed within the Canvas-integrated Microsoft 365 Copilot environment, with access restricted to students enrolled in ME 2220. Prior to classroom release, the system was tested by graduate laboratory assistants and instructors using representative student queries to verify response accuracy and clarity. Fig. 3 presents an example of the chatbot's interface and response style as experienced by students, demonstrating how the implemented design supports timely, course-aligned assistance while preserving academic integrity during the pilot study.

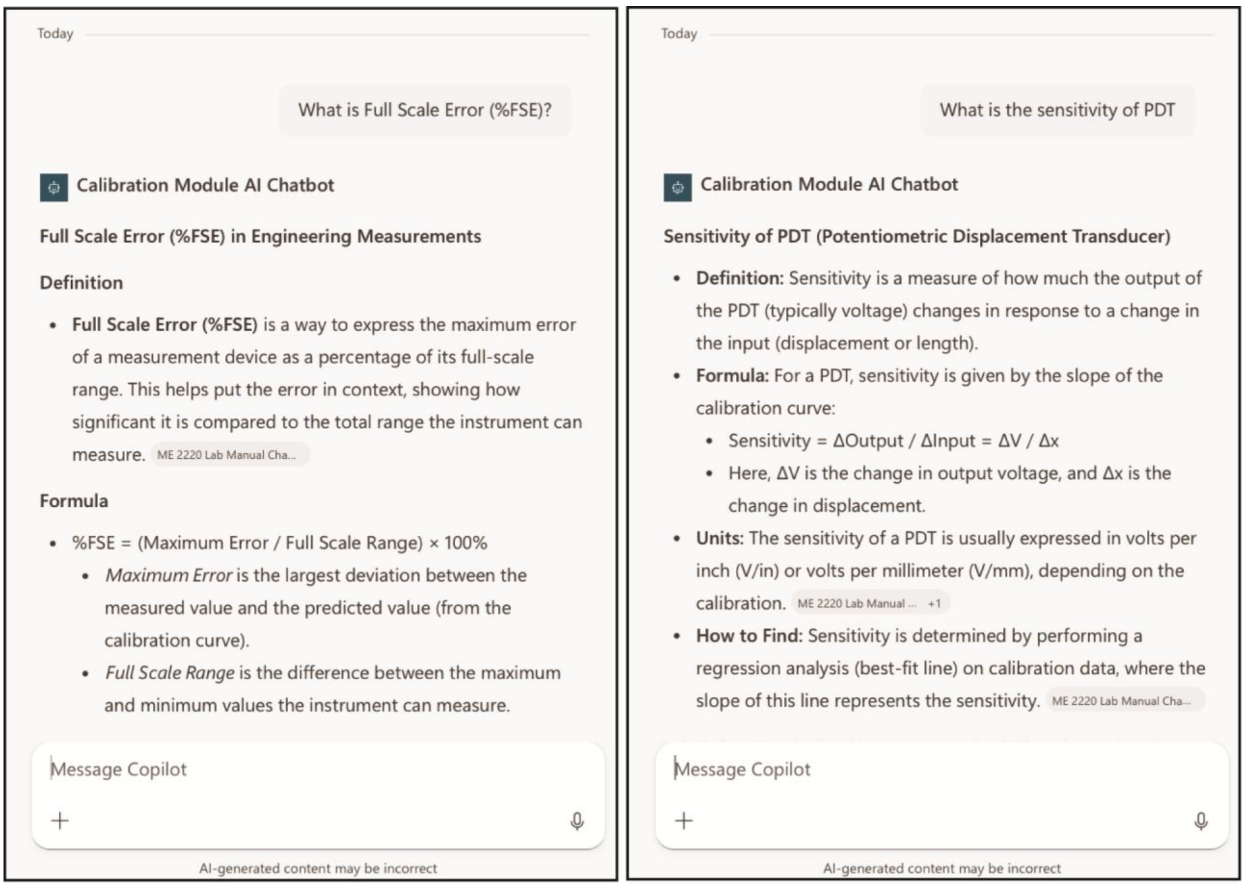

Fig. 3. Screenshot of Chatbot interface and response to a common question.

### 4.3 Observations and Results in the Course

During the first full week of the Spring 2026 semester, the pilot study was conducted after the Chatbot was developed in November-December 2025. The laboratory sections began on January 12 and met twice per week. Students were requested to complete pre-study reading in preparation for the on-site laboratory experiment. In Fig. 4, the bar chart displays the total number of conversations each day for the 40-student study population. The total number of conversations was 24, with 54% student engagement and an average of 2 daily users. Most conversations occurred mid-week.

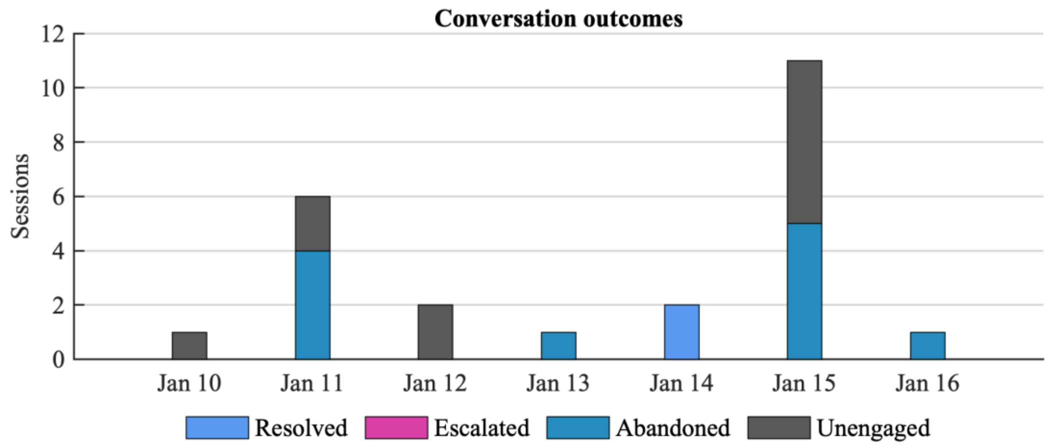


Fig. 4. ME 2220 pilot study chatbot conversations for week one.

The training materials available to the students are presented in Fig. 5 along with the percentage of student questions that the AI Chatbot referenced in each training source. For instance, the transcript for the training video was used to answer 75% of the students' questions. As expected, the students likely appreciated the Chatbot's ability to help guide their search for answers to posed and encountered experiment questions.

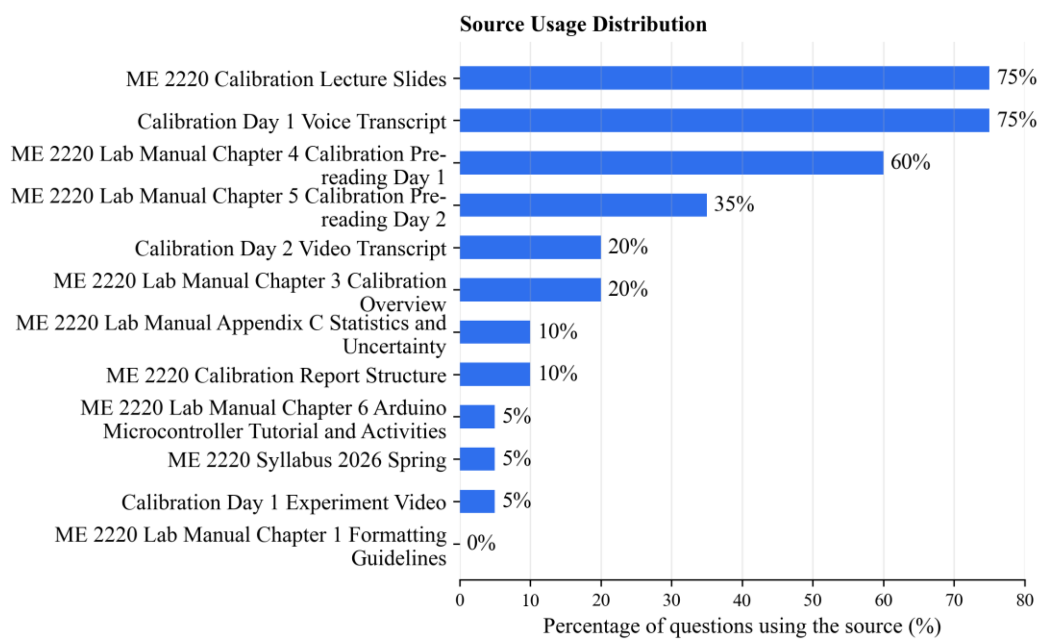


Fig. 5. Available resources for the Chatbot and percentage of questions answered with that source during the pilot study.

A detailed view of the Chatbot interaction with the training materials on a day-to-day basis is shown in Fig. 6. On January 13, the Chatbot referenced the Laboratory Manual Chapter 3 and presentation slides describing a broad overview, far more than any other content. However, on January 16, as students progressed through the experiment, the main sources were the video transcript and Laboratory Manual Chapter 4 on calibration theory and experiment details.

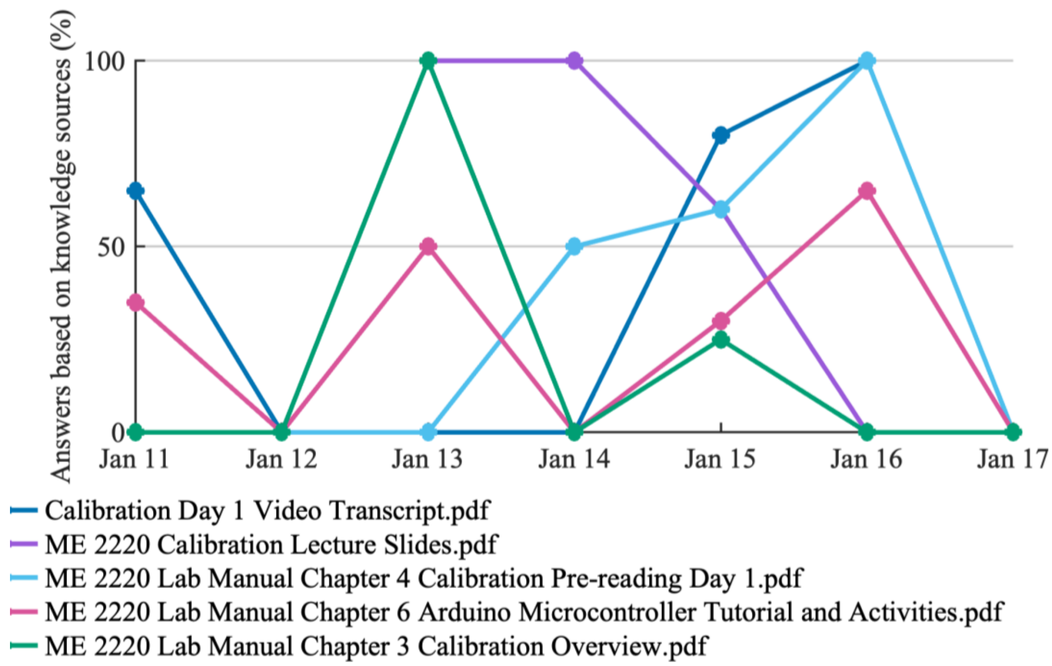


Fig. 6. Chatbot targeting ME 2220 lab knowledge sources daily during the pilot study.

The lab report scores were used to directly measure the student outcomes between the pilot sections with access to the AI tool and the control sections. The average report score across the 242 students in the 11 control sections was 3.9 out of 5, using a 5-point rubric. The average report score for the AI sections was also 3.9. The average report scores for each of the AI sections, representing 20 students each, were 3.7 and 4.1. So, the average report score for one of the AI sections was 0.2 lower than the average of the control sections, and the average report score for the other AI section was 0.2 higher than the average of the control sections.

In a holistic qualitative review of reports, the instructor coordinating all sections of the course observed the AI-assisted calibration report scores were consistent with those from control sections, confirming the quantitative results of similar average report scores.

Surveys completed after the module will be used to assess student engagement and perception in all sections. Preliminary results from the likert survey question, “This laboratory enhanced my understanding of engineering theory and/or practice”, indicate the pilot group provided higher responses overall than those in the control. Once all the survey results are available, a more comprehensive statistical analysis can be completed to assess the extent that more students in the pilot group agreed and the extent that they had stronger agreement. The preliminary results suggest that students perceived a benefit from access to AI tool.

Lastly, the research team took preventive measures to ensure the Chatbot would not write the laboratory's Calibration Report for the students. A trigger was created in which a student types "can you write my report?", "Can you just tell me the answer to the deliverable?" or "Can you do my experiment?" The automatic response received is "Whoa, Tiger! I'm here to help you learn, not do the work for you. Learning requires thinking, so let's dig in to theory, calculations, practice, applications, and communication".

## 5. Conclusion

Universities must thoughtfully embrace digital technology to advance student curriculum excellence. The availability of ML/AI tools enables the creation of chatbots that can aid in the delivery of undergraduate laboratory courses. Specifically, a chatbot was designed and implemented in a sophomore-level mechanical engineering class to assist students with answering their questions before/after the experiential activity. In this limited pilot study, results suggest students were willing to engage with the use of the optional AI chatbot to complete the lab activities and report, performed no worse on their lab reports, and perceived favorable experiences conversing with the chatbot. The results of this investigation have demonstrated that chatbots may hold promise to safely supplement the learning process in an undergraduate laboratory course.

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