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Abstract: This paper describes the design and evaluation of a new senior-level course of ***ENGR 4750: Mechanical Engineering Labs*** in the Department of Engineering, Engineering Technology, and Surveying at East Tennessee State University that integrates hands-on experiments across fluid mechanics, thermodynamics, and heat transfer to reinforce previously learned theory. The laboratory sequence includes Bernoulli flow measurement, turbine performance (Francis/Pelton), centrifugal pump characterization, pressure losses in a piping system, wind tunnel aerodynamics, four-stroke engine testing (diesel and petrol), cross-flow water-to-air heat exchanger analysis, and transient/conduction experiments in metals. The goals are to (i) strengthen students' conceptual understanding through experiment-theory alignment, (ii) develop measurement, analysis, and communication skills, and (iii) document student perceptions of learning value in a first-offering context.

A mixed-methods assessment plan is adopted. Three lecture sessions provide conceptual foundations for the experiments, five short post-lab quizzes test learning outcomes, and rubric-based reports capture data acquisition and result interpretation. In addition, students complete an end-of-course survey (5-point Likert scales + open-ended items) on perceived gains in understanding, confidence with instrumentation, and ability to connect models to real data. Engagement indicators such as lab attendance, teamwork during experiments, and on-time submissions are also tracked.

The WIP is expected to contribute in threefold: (1) sharing instrument set and alignment matrix mapping each lab to ABET student outcomes (e.g., experimentation and data analysis, communication, and engineering judgment); (2) reporting initial results from the first semester's deployment at a regional public university, including pre/post gains on targeted concepts, rubric-based performance trends, and student perceptions of value; and (3) demonstrating the application of an ABET-aligned experimentation rubric to evaluate student performance on a representative lab experiment. The rubric assesses setup, data collection, analysis, and conclusions, highlighting strengths, gaps, and targeted improvement actions. Embedding this evidence-based rubric into course evaluation illustrates how hands-on lab courses can both reinforce theoretical knowledge and provide measurable outcomes for accreditation and continuous improvement. This work provides an actionable template for programs launching or revising senior Mechanical Engineering laboratory courses, highlighting practical instruments, data collection strategies, and iterative improvements that other institutions can readily adapt.

Introduction

Laboratory courses are essential components of engineering education because they provide students with opportunities to apply theoretical concepts in real-world experimental contexts, develop measurement and data analysis skills, and build professional competencies that are difficult to achieve through lecture-based instruction alone [1, 2]. Prior research in mechanical and engineering laboratory education shows that thoughtfully designed lab sequences support critical learning objectives such as experimentation processes, data interpretation, technical communication, and alignment with industry expectations and accreditation outcomes [3, 4]. Mechanical engineering laboratory courses, in particular, have been used to reinforce core fluid mechanics, thermodynamics, and heat transfer concepts while promoting skills in engineering judgment [5, 6]. For example, Van Treuren demonstrated the value of using lab courses as assessment tools for ABET outcomes in senior mechanical engineering laboratories, highlighting the importance of structured assessment practices in laboratory instruction [7]. Gangwar and Ma assessed Student Outcome 6 (SO6-"develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions") through sophomore-level solid mechanics labs [8]. They detailed a series of innovative lab activities that scaffold student abilities in experiment design, data analysis, and engineering judgment. Other recent studies across multiple institutions further underscore the variability in lab report assignments and assessment design, and how these elements impact students' abilities to communicate experimental findings and engage in analytical thinking within engineering contexts [9, 10].

To provide students with opportunities to deepen their understanding of thermal-fluid systems, East Tennessee State University requires senior engineering students to complete a comprehensive mechanical engineering laboratory course (ENGR 4750) during the fall semester before their final year. This paper presents an evaluation of the newly developed ENGR 4750 course, which integrates hands-on experimentation with a structured assessment strategy. The laboratory sequence includes Bernoulli flow measurement, turbine performance (Francis/Pelton), centrifugal pump characterization, pressure losses in a piping system, wind tunnel aerodynamics, four-stroke engine testing (diesel and petrol), cross-flow water-to-air heat exchanger analysis, and transient/conduction experiments in metals. These activities are explicitly designed to strengthen conceptual understanding, enhance measurement and analysis skills, and document students' perceptions of learning value during the course's first offering. The work presented here is positioned as a work-in-progress evaluation of the course's implementation and assessment strategy. This work contributes in three key ways: (1) presenting instrument set and alignment matrix that map each laboratory to ABET student outcomes related to experimentation and data analysis, communication, and engineering judgment; (2) reporting preliminary results from the first semester's deployment at a regional public university, including learning gains on targeted concepts, rubric-based performance trends, and student perceptions of value; and (3) demonstrating the application of an ABET-aligned experimentation rubric to evaluate student performance on a representative laboratory experiment. The rubric assesses setup, data collection, analysis, and conclusions, highlighting strengths, gaps, and targeted improvement actions. Embedding this evidence-based rubric into course evaluation illustrates how hands-on laboratory courses can both reinforce theoretical knowledge and provide measurable outcomes for accreditation and continuous improvement. This work offers a practical and adaptable framework for programs launching or revising Mechanical Engineering laboratory courses.

Methodology

2.1 Course Context and Student Population

The study is conducted in a newly developed senior-level laboratory course, **ENGR 4750: Mechanical Engineering Labs**, offered for the first time in Fall 2025 in the Department of Engineering, Engineering Technology, and Surveying at East Tennessee State University. The course is a one-credit laboratory course designed for senior undergraduate engineering students who have previously completed foundational coursework in fluid mechanics, thermodynamics, and heat transfer.

A total of 10 senior undergraduate engineering students were enrolled in the course. All students had previously completed the relevant lecture-based prerequisite courses. Because only one set of experimental equipment was available for each laboratory, the ten enrolled students were organized into three groups for the duration of the semester. Laboratory activities were therefore designed to emphasize efficient use of limited resources and were conducted weekly. During each experiment, groups conducted tests using different operating parameters, allowing the whole class to generate a broader dataset within the available time. The resulting data were shared across groups to enable comparison of multiple operating conditions and to support a more comprehensive understanding of system behavior. While experiments and data collection were performed collaboratively, each student was required to submit an individual lab report to ensure independent analysis, interpretation, reflection on the experimental results, and technical communication. Because the students had progressed through much of the curriculum together prior to this course, group formation was straightforward and conducted randomly through the course management system (D2L), with no reported collaboration issues.

2.2 Laboratory Structure and Instructional Design

The course was structured around ten planned laboratory experiments distributed across the semester, with three lecture sessions interspersed to reinforce key theoretical concepts relevant to upcoming experiments. The lectures were designed to prepare students for experimental work by providing conceptual scaffolding. The planned laboratory schedule is shown in **Table 1**, which includes experiments covering fluid mechanics, turbomachinery, internal combustion engines, heat exchangers, and heat conduction. Each laboratory was supported by a detailed lab manual that included the purpose of the experiment, descriptions of laboratory equipment, step-by-step experimental procedures, and required data collection guidelines. These manuals were intended to guide students through proper experimental practice while encouraging critical engagement with theory and results. Except for Lab 6 (Wind Tunnel), all laboratory manuals were developed based on the equipment manuals provided by the manufacturer, as the laboratory equipment used in the course was supplied by a single vendor (TecQuipment). These manuals were adapted to align with course learning objectives and included detailed experimental procedures, data collection guidelines, and analysis expectations. For Lab 6, which utilized wind tunnel equipment (Aerostream Wind Tunnel) from a different manufacturer for which a detailed instructional manual was not available, experimental procedures and analysis expectations were delivered through in-class instruction and demonstration. During the laboratory session, the instructor provided guidance on experimental setup, data collection, and data analysis to ensure consistency with the learning objectives and assessment framework used throughout the course.

Due to equipment availability issues, Lab 7 (diesel engine test) could not be conducted during this semester. This did not significantly affect the course learning objectives, as Lab 8 (petrol engine test) followed nearly identical procedures and theoretical principles, differing primarily in input fuel materials. Students were therefore still exposed to the intended concepts, and a post-lab quiz reinforced understanding of engine performance mechanisms.

Table 1 The course schedule.

Course schedule	
Lecture I	
Lab 1 Flow Measurement Methods	
Lab 2 Laboratory-scale Francis Turbine Performance Analysis	Quiz
Lab 3 Laboratory-scale Pelton Turbine Performance Analysis	
Lecture II	
Lab 4 Centrifugal Pump Test	Quiz
Lab 5 Pressure Losses in Piping System	Quiz
Lab 6 Wind Tunnel	
Lecture III	
Lab 7 Laboratory-scale Four Stroke Diesel Engine Test	
Lab 8 Laboratory-scale Four Stroke Petrol Engine Test	Quiz
Lab 9 Crossflow Water to Air Heat Exchanger Test	
Lab 10 Linear Heat Conduction Test	Quiz

2.3 Assessment Framework

To evaluate the effectiveness of the laboratory course and to examine its impact on student learning, a mixed-methods assessment approach was employed, incorporating both direct and indirect measures.

2.3.1 Direct Assessment

Direct assessment consisted of post-lab quizzes (10%) and individual laboratory reports (50%). Five quizzes were administered throughout the semester, each associated with selected laboratory experiments (Table 1). Each quiz contained five multiple-choice questions designed based on the lab manual and targeted key experimental concepts, procedures, and theoretical relationships to evaluate student conceptual comprehension. Laboratory reports served as the primary direct assessment of students' experimental competencies. Reports were evaluated using an ABET-aligned experimentation rubric, which assessed students' abilities to a) Collect and analyze data using correct methods, b) Apply relevant theoretical principles, c) Interpret results and draw evidence-based conclusions, and d) Communicate findings clearly and professionally. The grading criteria emphasized clarity of experimental strategy, accuracy of data analysis, proper use of units and equations, comparison with theoretical expectations, and the quality of technical writing. These reports provided insight into how students think through experimental problems and frame their findings in a logical engineering format.

2.3.2 Indirect Assessment

Indirect assessment was conducted through an anonymous end-of-course student perception survey, administered at the conclusion of the semester. The survey aimed to capture students' perspectives on the effectiveness of the laboratory course and its impact on their learning. Survey questions focused on a) Perceived improvement in understanding previously learned concepts, b) Confidence in using laboratory equipment and instrumentation, c) Ability to connect experimental results with theoretical models, d) Effectiveness of experiment design and course organization, and e) Perceived preparedness for real-world engineering practice. All survey items used a 5-point Likert scale, ranging from "Strongly Disagree" (1) to "Strongly Agree" (5), with two additional open-ended questions allowing students to provide qualitative feedback. The survey questions are summarized in **Table 2**.

Table 2 Student Perception Survey

		Rating Scale				
		1	2	3	4	5
		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Q1	The lab activities helped me better understand theoretical concepts from fluid dynamics, thermodynamics, and heat transfer					
Q2	The experiments improved my ability to connect mathematical models with real-world measurements and data					
Q3	The labs increased my confidence in using engineering instruments and measurement systems					
Q4	I am more confident in analyzing data and results after completing these labs					
Q5	The lab manuals and instructions were clear and supported my learning					
Q6	The sequence of labs was logical and helped build my understanding progressively					
Q7	The time allocated for each experiment was sufficient to complete the tasks and reflect on the results					
Q8	These lab experiences increased my interest in applying theoretical knowledge to practical engineering problems					
Q9	I believe the skills gained in this course (data collection, analysis, communication) will transfer to my professional practice or future studies					
	Open-ended Survey					
Q10	What aspect of the lab course was most helpful for your learning?					
Q11	What suggestions do you have for future improvement?					

In addition to formal assessments, several engagement indicators were tracked to contextualize student performance, including lab attendance, teamwork during experimental activities, and on-time submission of assignments (40% in total). While not used as standalone measures of learning, these indicators provided supplementary information regarding student participation and consistency throughout the course.

By combining rubric-based evaluation of lab reports, quiz performance, student perception surveys, and engagement indicators, the methodology provides a comprehensive view of both student learning outcomes and student experiences in this first-time-offered laboratory course. This mixed-methods framework supports data-driven course evaluation and informs continuous improvement efforts by evidencing the effectiveness of these learning experiences in fostering students' development as capable, independent engineers.

3. Results and Preliminary Findings

Preliminary results from the end-of-course student perception survey were analyzed based on responses from six of the ten enrolled students at the time of data collection (Figure 1). Although the response rate is partial (60%), the results provide early insight into students' perceptions of the effectiveness of the course. Overall, student responses were strongly positive across all survey items, with the majority of responses falling within the "Agree" and "Strongly Agree" categories. No responses were recorded in the "Strongly Disagree" or "Disagree" categories, and only one response appeared in the "Neutral" category.

Responses to Questions Q1 and Q2 indicate that students perceived the laboratory activities as effective in reinforcing theoretical concepts from fluid mechanics, thermodynamics, and heat transfer, and in helping them connect mathematical models with real-world measurements. For both questions, five out of six respondents selected "Strongly Agree", while the remaining response was "Agree". These results suggest that the hands-on experiments successfully supported experiment–theory alignment, which was a central goal of the course. Similarly, Q8 results indicate increased student interest in applying theoretical knowledge to practical engineering problems. Most respondents selected "Strongly Agree", with the remainder selecting "Agree", suggesting that the laboratory experiences positively influenced student motivation and engagement with engineering applications.

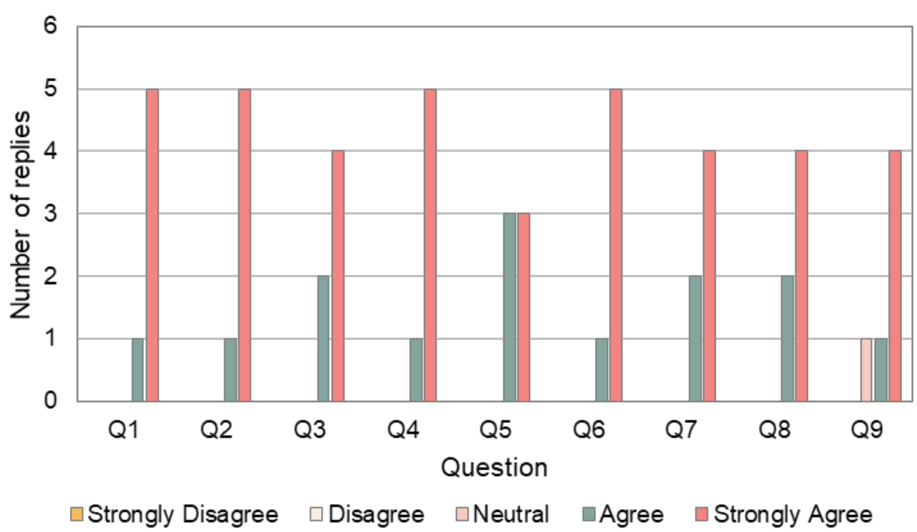

Figure 1 Survey results.

Questions Q3 and Q4 focused on students' confidence in using engineering instruments and analyzing experimental data. Responses show that all six students reported positive outcomes, with most selecting "Strongly Agree" and a smaller number selecting "Agree". These findings indicate that the laboratory course supported the development of practical experimental skills, including measurement system usage and post-experiment data interpretation. The positive responses to Q4, which addressed confidence in analyzing data and results, are particularly noteworthy given the course emphasis on comparison with theoretical models and structured lab reporting.

Student perceptions of course organization and instructional support were captured in Q5 to Q7. Responses to Q5 suggest that students generally found the lab manuals and instructions to be clear and supportive of learning, with an even distribution between "Agree" and "Strongly Agree". This result suggests that the manuals provided sufficient guidance while still allowing students to engage critically with the experiments. Responses to Q6 indicate strong agreement that the sequence of laboratories was logical and progressively built understanding, supporting the course's scaffolded design across fluids, thermodynamics, and heat transfer topics. For Q7, students agreed that the time allocated for each experiment was sufficient. This suggests that while the overall pacing was appropriate, certain experiments may benefit from additional time or pre-lab preparation in future offerings.

Question Q9 addressed students' perceptions of skill transfer to professional practice or future studies. Responses were generally positive, with most students selecting "Strongly Agree", one selecting "Agree", and one selecting "Neutral". This finding suggests that most students recognized the relevance of skills developed in the course—such as data collection, analysis, teamwork, and technical communication—to real-world engineering contexts.

Open-ended survey responses provided additional insight into students' learning experiences and areas for improvement. A consistent theme across responses was the value of hands-on learning and practical application. Multiple students emphasized that direct interaction with laboratory equipment enhanced their understanding of engineering concepts and strengthened connections to material learned in prior lecture courses. Several students also highlighted the development of transferable technical skills, particularly technical writing and data processing, noting that the course improved their ability to use tools such as Microsoft Excel and to communicate results effectively in written reports. These comments align with the course's emphasis on individual lab reports and structured data analysis. Representative comments included:

What aspect of the lab course was most helpful for your learning?

- *"Practical application and hands-on experience with engineering concepts."*
- *"What I found helpful was actively participating in each lab and fully understanding the equipment. This allowed me to not only get hands-on with the lab equipment but also understand the theoretical aspect of what the lab is covering as well."*
- *"It was very useful to be able to see how the material we learned in other classes applies to real applications."*
- *"The hands-on learning was the most helpful. It improved my technical writing."*

- *"The labs themselves were very useful. I found the methodology and explanations of the professor to be the most helpful."*
- *"This lab course allowed me to learn Microsoft Excel and improve my technical writing, which has aided me in a lot of other courses and engineering topics this semester."*

In addition to positive feedback, students also provided constructive recommendations for course improvement, primarily related to laboratory reports and quizzes. Common suggestions included providing examples of high-quality lab reports, clarifying expectations and grading criteria, and increasing the number of quizzes—including the use of practice quizzes—to better support learning and reduce the weight of individual assessments. These recommendations offer actionable guidance for continuous improvement and directly inform planned revisions to future offerings of the course. Representative suggestions included:

Suggestions for course improvements

- *"Give an example of a good lab report for students to base theirs off of."*
- *"Lab reports could be condensed slightly (most of them ended up being very lengthy and time-consuming)."*
- *"Better consistency in grading scales and clearer expectations for student work would greatly help students to understand where they should be improving in lab reports and data collection."*
- *"Give 1 quiz for each lab (or just a few more quizzes) to make each quiz worth a smaller percentage and/or drop the lowest 1-2 quizzes. Consider dropping the lowest lab report grade."*
- *"The class was very good and very helpful!"*
- *"Add practice quizzes."*

These preliminary survey results indicate that students perceived the laboratory course as effective in a) reinforcing theoretical concepts through hands-on experimentation, b) increasing confidence in experimental instrumentation and data analysis, c) providing a logically structured and well-supported learning experience, and d) developing transferable skills relevant to professional engineering practice. While these results are based on a partial response set, they provide encouraging early evidence supporting the course design and assessment framework.

4. Discussion

4.1 Interpretation of Preliminary Findings

The preliminary findings suggest that the newly implemented laboratory course effectively supported its primary instructional goals, particularly in reinforcing theoretical concepts through hands-on experimentation and developing students' confidence with experimental practices. Survey responses indicate strong perceived gains in conceptual understanding and in the ability to connect mathematical models with real-world measurements, which aligns with the course's emphasis on experiment–theory integration across fluid mechanics, thermodynamics, and heat transfer. Students' high levels of agreement on items related to instrumentation use, data analysis, and result interpretation suggest that the laboratory experiences contributed meaningfully to experimental skill development. These outcomes are consistent with prior research emphasizing the role of structured laboratory experiences in fostering practical engineering competencies [4, 7]. Importantly, the combination of survey results and student comments indicates that learning gains were not limited to conceptual understanding, but also extended to transferable skills such as data processing, technical writing, and professional communication.

4.2 Alignment with ABET Experimentation Outcomes

A key contribution of this work is the integration of an ABET-aligned experimentation rubric as both an assessment and reflective tool. The rubric explicitly targets core components of ABET SO6, including experimental setup, data collection, analysis, and evidence-based conclusions [1, 11]. Specifically, the SO6 emphasizes the ability to *develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions* [8]. Preliminary rubric-based observations, such as students' strengths in identifying appropriate tests and applying theoretical equations, alongside gaps in calibration checks and uncertainty analysis, provide concrete evidence of where students meet or exceed expectations and where further instructional support is needed. The consistency between rubric findings and student feedback strengthens the validity of the assessment approach. For example, students reported increased confidence in analyzing data and writing technical reports, which aligns with rubric strengths observed in data interpretation and conclusion development. Conversely, student requests for clearer expectations and example reports correspond directly with rubric-identified variability in report clarity and reproducibility. This convergence suggests that the rubric not only measures learning outcomes but also serves as a diagnostic instrument to guide instructional improvement.

4.3 Role of Course Design and Instructional Scaffolding

The scaffolded structure of the course, i.e., interleaving lectures with progressively complex laboratory experiments, appears to have supported cumulative learning. Strong agreement regarding the logical sequencing of laboratories suggests that students perceived coherence across topics, even as the course transitioned between disciplines. This is particularly important in a senior laboratory course where students are expected to synthesize knowledge from multiple prior courses. However, student feedback related to workload, pacing, and grading consistency highlights areas where instructional scaffolding can be further refined. The neutral response to the item on transfer of skills to professional practice suggests an opportunity for further improvement in course design. Specifically, instructional scaffolding can be strengthened by making connections between laboratory activities and real-world engineering applications more explicit. This may be achieved through additional industry-context examples, reflection prompts, or applied case discussions. These findings underscore the importance of clearly defined expectations and exemplars in laboratory courses, especially during a first offering.

4.4 Implications for Laboratory Course Design and Assessment

Taken together, these results suggest that combining hands-on experimentation with rubric-based assessment and student feedback mechanisms provides a robust framework for evaluating and improving laboratory courses. The use of multiple assessment modalities provides complementary perspectives on student learning, strengthening confidence in the observed outcomes. For programs seeking to document accreditation-related evidence while simultaneously enhancing student learning, this approach demonstrates how laboratory courses can serve dual roles: reinforcing disciplinary knowledge and providing measurable, outcome-aligned assessment data. While the present findings are preliminary, they indicate that structured assessment practices embedded within laboratory instruction can support both pedagogical effectiveness and continuous improvement processes.

4.5 Limitations of the Current Study

The survey results reported here are based on a small sample size, a partial response set, and data collected from a single semester, reflecting the first offering of the course. These limitations restrict generalizability and preclude strong causal claims. However, these preliminary results provide a foundation for expanded data collection, longitudinal analysis, and cross-cohort comparison in future offerings of the course. Importantly, the insights gained from both quantitative and qualitative data directly inform planned course refinements, including enhanced guidance for laboratory reporting, increased emphasis on calibration and uncertainty analysis, and adjustments to assessment structure.

5. Conclusion and Future Work

This work-in-progress paper presents the design, implementation, and preliminary assessment of a newly developed senior-level Mechanical Engineering laboratory course. Early evidence from mixed-methods assessment, including rubric-based evaluation, quizzes, and student perception surveys, suggests that the course effectively supported experiment-theory integration, development of experimental skills, and confidence in data analysis and technical communication. The use of an ABET-aligned experimentation rubric provided structured insight into student strengths and areas for improvement, directly informing targeted course refinements. Although the findings are preliminary and based on a first offering with a limited sample size, the assessment framework and continuous improvement strategies described here offer a practical and replicable approach for evaluating and enhancing senior engineering laboratory courses. These findings will guide future iterations of the course, with a focus on clearer guidance and feedback for lab reports, increased student engagement during laboratory sessions, and continued improvements in laboratory efficiency to better support student learning and professional development.

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