2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
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ASEE
Paper ID #37083

A Laboratory Course Design Strategy to Increase Student Confidence: Connecting Material Testing Standards to Course Material and Real Applications

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Abstract

This paper presents a laboratory course design strategy to align material testing standards with hands-on experiments, game-based learning, and real-world application. The goal of this strategy is to strengthen the student's ability in understanding and applying material testing standards. This work presents two case studies that applied the same approach, with one case focusing on the characterization of mechanical material properties and the other on thermofluid properties. In each case, the four-week laboratory module began with the following material selection questions: "Which of the materials provided should be selected to build a turbine blade?" or "Which of the provided glycol-water mixtures is the best engine coolant for cold weather?" Students had to conduct multiple material tests, compare their experimental results to literature with statistical considerations, and predict what the provided materials were to answer the selection question. Each experimental procedure was adapted from American Society for Testing and Materials (ASTM) standards, and students were asked to highlight any differences. We embedded game-based learning using Kahoot! in lectures to motivate students and help them comprehend each ASTM standard. In addition, students were given an opportunity to design their own experimental protocol within the module. The module culminated in a conference paper-style report where the students selected the ideal material to answer their selection questions. They needed to support their decision by following a guided analysis using their experimental results. For example, analyzing a heat exchanger's performance based on the thermofluid property values obtained from their experiments for each unspecified specimen. After completing the four-week laboratory module, our survey data indicated that 91% of the students (n=157) are confident or very confident in their abilities to apply the same ASTM standard in the future, and 78% are confident or very confident they can follow a new ASTM test standard. The majority (84%) of the students agreed that the activities helped them understand the real-world application of the theory they had learned in their Mechanical Engineering (ME) curriculum. Additionally, 76% of the students agreed they applied knowledge from their past ME courses to these lab activities. We concluded hands-on experiments were consistently the most encouraging activities that motivated students to read and understand the ASTM standards disregarding the class size and topics.

I. Introduction

Understanding engineering codes and standards are undoubtedly essential for success in an engineering career. Engineering curricula need adequate training to prepare students to remember, understand, and apply these professional standards. Based on the Revised Bloom's Taxonomy [1], Remembering, Understanding, and Applying are lower-order thinking skills that then help develop critical thinking skills. The laboratory course design strategy discussed in this paper is the second quarter of a four-level senior mechanical engineering laboratory course developed to enhance students' higher-order thinking skills [2].

Engineers are known to be hands-on problem solvers; however, multiple factors have shaped many engineering and science laboratory curricula into cookbook models. Some leading factors include a lack of resources, a large student population, institutes' focus on research, and a lack of incentives to support, compensate, and motivate faculty to spend the demanding time and effort needed to develop a quality laboratory experience [3] Students follow step-by-step procedures, collect data, and apply given equations to obtain a result and conclusion for submission. These experiments check the ABET statement to "conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions." but do not truly apply the logical thinking necessary to fulfill the "develop" requirement or to solve real-world problems [4]–[6]. Additionally, consider the ABET curriculum design requirement where "The curriculum must include a culminating major engineering design experience that incorporates appropriate engineering standards and multiple constraints and is based on the knowledge and skills acquired in earlier course work." We believe the engineering design experience should not be the only time where students apply standards and link prior coursework to real-world applications. This belief is the core motivation behind the laboratory course design presented in this paper. This is a unique approach that sets our course design apart by focusing every experiment on equipping the students to determine the solution to an engaging, real-life problem. This paper will provide a teaching model for small and large class sizes and a laboratory course design strategy that motivates students to apply their lower-order thinking skills, increase their confidence in transferring skills to new applications, and realize the theory from their curriculum in real-world applications.

Since Materials is a fundamental ME knowledge our program identified, we choose to emphasize American Society for Testing and Materials (ASTM) standards in our laboratory course. After completing the four-week laboratory module, students will gain hands-on experience conducting material property measurements by following standard procedures. They will understand relevant ASTM standards by studying the details listed on the standard, comparing them to their experimental process, and following the data analysis methods and reporting format. In this paper, we present two case studies, one for mechanical material properties characterization and another for thermophysical material properties. We collected student feedback for three continuous semesters in class sizes ranging from 24 to 192 students.

II. Method

a. The Course Structure

The same material characterization laboratory course design strategy was applied to our senior-level laboratory course for three semesters at different scales. It began as a small-scale pilot course for 24 students where they attended the same lecture but were split into two lab sections of twelve students. We offered the pilot for two semesters with different topics before the course became a core, required course. The full-scale offering included 192 students enrolled in the Fall 2022 semester. In the first pilot, the multiple-week material lab modules were focused on thermo-fluid material properties, presented below in the first case study. The second pilot emphasized mechanical material properties presented in the second case study. In the full-scale class, both topics were offered in parallel, with half of the class attending lectures on thermo-fluid material properties and the other half attending lectures on mechanical material properties. Each student was only required to complete one of the two options. With our equipment and laboratory arrangement, each lab section was able to simultaneously support four teams of students for each material option. Thus, a total of eight teams were able to work in the lab at each lab section. We split the 92 students in each material option into eight lab sections. As a result, 24 students, combining both material options and organized into eight teams of three, simultaneously conducted experiments in the lab. The structure of the single-topic pilot modules and the dual topics full-scale offering is summarized in Figure. 1.

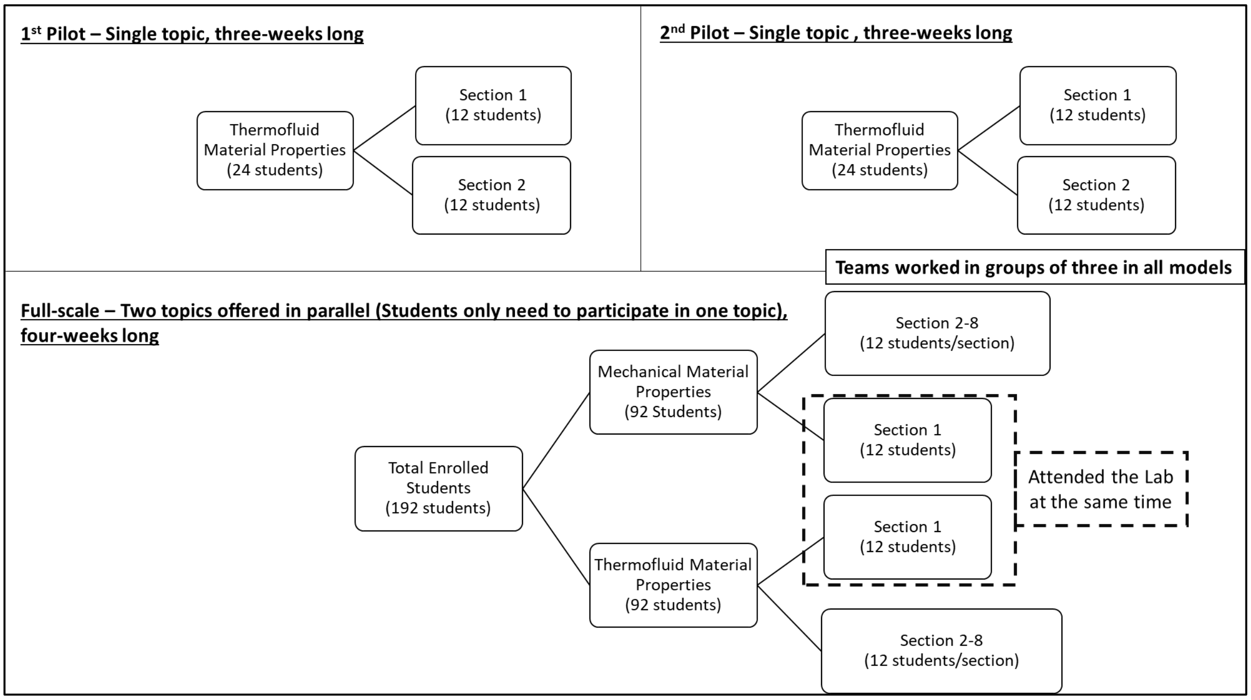

Figure 1. Student distribution in the single-topic pilot and dual topics full-scale offering.

The same class model was applied for both the pilot and full-scale offering, except the three-week-long material modules were extended to four weeks for the full-scale offering. This extra week was added to provide more time for students to complete their work, as suggested by the students in the pilot courses. Students attended two fifty-minute lectures and a three-hour-long laboratory section each week of the materials module. The lectures reviewed related engineering concepts and statistical knowledge, discussed the lab report format, and embedded gamification using Kahoot! to encourage students to read and understand the details listed on the ASTM standards. During the lab, teams performed material tests on three unspecified specimens during the first few weeks by following a provided protocol that was modeled after an ASTM standard. Students compared their experimental results with relevant literature to predict their material specimen's composition. In the last week of the labs, the teams shared their collected data to perform statistical analysis and conduct theoretical calculations to answer a prescribed material selection question connecting the multiple-week module. Each week students' team summarized their results in a short submission and answered discussion questions which guided them to understand the data. At the end of the module, each team documented their experiment results as a conference paper. The paper's abstract was provided together with a writing guide specifying the format and expectations for each section of the paper. Other deliverables of the course included weekly pre-labs to prepare students before each experiment and a lab submission that documented their results and included concept discussions. Table 1 summarizes the course structure of the pilot and full-scale offering.

Table 1. Lecture and Lab Structure of the Pilot and Full-scale Offering.

Pilot	Full Scale offering	Lectures (50 mins each)	Lab Activities (3 hrs/wk)
Week 1-2	Week 1-3	Mon, Fri	Students rotated among 2-4 material testing experiments.
Week 3	Week 4	Mon, Fri	Perform statistical analysis (Teams shared experiment data) and theoretical analysis to compare material performance and answer a real-world problem.
Lab Report			Complete a 4-6 pages conference paper

b. Key Design Components

The design of our material characterization module included six essential components.

1. **Identify the purpose** - Connect the multiple-week activities with one real-world question.
2. **Allow investigation** - Provide unspecified materials for students to investigate and predict the material composition by comparing their experimental data with literature.
3. **Hands-on experimentation** - Allow students to perform the experiments from the start to the end and provide enough opportunities for each team member to get a chance to operate the equipment.
4. **Perform statistical analysis** - Teams shared their data and conducted statistical analysis to compare the material properties between specimens. Data sharing allows students to cross-validate their experimental results and encourages discussions about the cause of any errors.
5. **Apply collected data to answer real-world problems** - Allow students time to evaluate their collected data to answer the real-world question connecting the multiple-week lab.
6. **Reinforce the ASTM standard at every step** - Each related ASTM standard was reinforced four times in our course design.

    a) Prelab - focused on lab safety and set expectations for the experiment.
    b) Lab Report - required all reporting formats to follow the requirement by the standard.
    c) Lab Protocol and Report - sometimes, our lab protocols intentionally deviated from the standard procedure under the criteria that these changes would not affect students' understanding and learning in operating the devices. Students were required to identify the similarities and differences between the lab protocol and ASTM procedure in their lab reports.
    d) Kahoot! - One lecture was designed to test students' understanding of the ASTM procedure and increase their awareness of critical details listed in the ASTM standards. This was conducted as a Trivia game for students to earn bonus points for the class. Students were allowed to participate in teams, and the game was conducted in an open-book format to create a low-pressure environment for students to learn.

c. The Course Design Assessment Method

Student feedback was collected after students completed the multiple-week module. A five-point Likert scale was used to assess the students' interest levels in the course activities, their confidence level in repeating the procedures, their confidence in applying new ASTM standards, and the helpfulness of the course design in guiding them in correlating engineering principles from their curriculum to real-world applications. In addition, students ranked the usefulness of six different activities in encouraging them to read and understand the ASTM standards and rated the effectiveness of the Kahoot! Trivia games. In the first pilot, 22 out of 23 students participated in the pre-survey, and all 23 students participated in the post-survey. In the second pilot, 13 out of 23 students completed the post-survey. In the full-scale offering, 69 out of 89 students completed the post-survey for the same lab topic as the first pilot, and 82 out of 89 students completed the post-survey for the lab topic identical to the second pilot.

III. Case Studies

a. Case I – Thermofluid Material Properties Lab

The four-week Thermofluid material property lab focused on one real-world question: "Which of the provided glycol-water mixtures is the best engine coolant for cold weather?" Students analyzed engine coolant performance between three fluids given as unknown propylene glycol-to-water ratios, simply labeled A, B, and C. They were asked to perform viscosity, specific heat capacity, thermal conductivity, and density for each to predict the propylene glycol-to-water ratios. The students performed experimentation during the first three labs by following the provided protocol modified from the relevant ASTM procedure. Except for the density lab, each team of three students was provided access to eye droppers, a precision pipette, graduated cylinders, and a precision scale. Then they were asked to develop their own protocol to measure the density and calculate the potential glycol-to-water ratio for each sample. Four student teams rotate through three experiment stations to minimize the development cost in three weeks. Those were the viscosity station, the specific heat capacity station, and the thermal conductivity and density station. The rotation table is summarized in Table 2.

Table 2. Lecture and Lab content of the Thermofluid Material Properties Lab

Lecture (Monday)	Lecture (Friday)	Lab			
		Team 1	Team 2	Team 3	Team 4
Introduction to the Thermofluid properties Lab	Review heart transfer in engine cooling system	Specific Heat Capacity	Specific Heat Capacity	Viscosity	Thermal Conductivity and Density
ASTM Trivia	Statistics II - Student's t test	Thermal Conductivity and Density	Viscosity	Specific Heat Capacity	Specific Heat Capacity
Statistic IV - Error Propagation	Review heart transfer in engine cooling system I	Viscosity	Thermal Conductivity and Density	Density and Thermal Conductivity	Viscosity
Review heart transfer in engine cooling system II	Lab Report Discussion	Radiator Analysis, Statistics and Lab Report			

For the viscosity measurements, students reviewed ASTM procedures D445 and D446 [7], [8] and compared them to the protocol they were given. Ubbelohde viscometers were used to measure the kinematic viscosity. For the specific heat lab, the students reviewed ASTM standard E1269-11 [9] and compared it to the protocol they were given. An Ohaus Pioneer PX85 scale, with TA Tzero pans and TA Tzero hermetic lids with the TA Discovery 25 Differential Scanning

Calorimetry (DSC), was used. Lastly, for the thermal conductivity lab, the students reviewed ASTM Standard D7896 [10]and measured the conductivity of each sample using a Thermtest THW-L2 unit. The provided lab protocols were modified from the ASTM standard. Changes were made to reduce the complications in handling the equipment. We ensured these changes would not affect the hands-on learning outcomes. For example, the water bath was removed from the viscosity measurement to simplify the operation without affecting students learning of how to use a viscometer. Due to the limitation of course time, each student's team performed each measurement once.

In the last week (week 4), the teams generated a database containing multiple measurements of each sample by sharing their data. Students statistically validated the uniqueness of each sample via t-tests and deduced the glycol-to-water ratio of each sample. The material selections lab ends by answering the real-world problem connecting the whole lab's activities: "Which of the provided glycol-water mixtures is the best engine coolant for cold weather?" To determine this, the students evaluated the heat dissipation of a single-pass, plate-finned, compact heat exchanger via an ε-NTU radiator analysis using the averaged material properties obtained from their experiments.

b. Case II – Mechanical Material Properties Lab

The four-week Mechanical material property lab focused on one real-world question: "Which of the materials provided should be selected to build a turbine blade?" Students were given three unknown metal specimens and asked to perform tensile testing, hardness testing, and density measurements to predict what each specimen was made of. This module's additional objective was to emphasize how manufacturing processes, particularly the printing orientation in additive manufacturing, affect the material properties. Additionally, the students performed fracture analysis on three overload failure specimens. These specimens were all made from the same material using different manufacturing processes. One was cut from a sheet of metal, and the other two were 3D printed in two different orientations. Students studied the overload fracture surface to investigate the resulting differences in properties.

Similar to the Thermofluid Material Lab (Case I), students performed experimentation for the first three labs by following the provided protocol modified from the relevant ASTM procedure, except for the density lab, where each team of three students was provided access to graduated cylinders, calipers, rulers, and scales. Then they were asked to develop their own protocol to measure the density of broken tensile testing specimens. Four student teams rotate through three experiment stations, the density and hardness station, the tensile testing station, and the failure analysis station. The rotation table is summarized in Table 3.

Table 3. Lecture and Lab Content of the Mechanical Material Properties Lab

Lecture (Monday)	Lecture (Friday)	Lab			
		Team 1	Team 2	Team 3	Team 4
Mechanical Material Properties Overivew + Report Format	Mechanical Material Properties and Data Analysis	Density and Hardness	Failure Analysis (Microscope + SEM)	Failure Analysis (SEM + Microscope)	Hardness and Density
ASTM Trivia	Statistic II - Error Propagation	Tensile Testing	Tensile Testing	Hardness and Density	Failure Analysis (Microscope + SEM)
Statistics III - Student's t test	Material Selection I	Failure Analysis (Microscope + SEM)	Hardness and Density	Tensile Testing	Tensile Testing
Material Selection II	Lab Report Discussion	Material Selection, Statistics and Lab Report			

For the tensile testing, students reviewed ASTM procedure E8/E8M [11] to complete their prelab, calculate machine operation parameters, compare it to the protocol they were given, and report their experimental results. An MTS Tensile Testing Machine (MTS EXCEED E43.504) was used together with an axial extensometer (Model 635.50F-25). For the hardness lab, the students reviewed ASTM standard E18 [12], and a digital Rockwell hardness tester (the Mitutoyo HR-530) was used. Lastly, a desktop Scanning Electronic Microscope (SEM) (NanoImages, SNE-4500M Plus) with Energy-dispersive X-ray spectroscopy (Bruker XFlash® 630 EDS) and a Stereo Zoom Microscope (Amscope, ZM-4TW3-FOR-9M) was used for students to perform fracture surface analysis and element analysis.

In the last week (week 4), four teams in the same lab section shared their data. Students then analyzed and evaluated if the material properties between the three specimens were statistically significant. The material selections lab ends by answering the real-world problem connecting the whole lab's activities: "Which of the materials provided should be selected to build a turbine blade?" Students evaluated the design requirement of a turbine blade, then extracted the performance index for different given constraints and applied the Ashby chart for material selection. In addition, students discussed their choice when safety, manufacturability, global, environmental, and economic factors were considered.

c. Lectures and Kahoot!

Two lectures per week were scheduled to introduce new concepts and review prior knowledge students needed to complete the lab, including statistics, heat transfer in engine cooling systems for the Thermofluid Material Properties Lab, and material selection in the Mechanical Material Properties Lab. One lecture early in the module (the third lecture) was reserved for a Kahoot-based ASTM standard Trivia. It covered essential details in the ASTM standard needed to understand and safely conduct each experiment. Our strategy to create a less stressful environment that encouraged students to read the procedures is the trivia only generated bonus points toward their final grade. Students were allowed to work in teams and reference any material during the game. The last lecture was scheduled for lab report discussion, which focused on writing a report that followed a conference paper format. This followed a key purpose in this laboratory course design to include a diverse lab report format instead of traditional lab reports. Our course used different communication tools, such as reports, including conference papers, email responses, and video journals. [2]In their conference paper report, the students were required to present their material properties and testing by following the format listed in the Report section of the corresponding ASTM standards.

IV. Result and Discussion

A week after completing the four-week material modules, the students were surveyed to gauge their self-confidence, understanding of theory and application and the effectiveness of the different activities in the course. This data is used to determine how effective the course was in training the students to remember, understand, and apply their previous course knowledge and the ASTM standards. The data for each offer is separated for the two cases (Thermofluid vs. Mechanical) when the data differed and is combined when the deviation was within a few percentage points. For the full-scale offering, there were n=75 students that completed the Thermofluid survey and n=82 for Mechanical. In the pilot offering, there were n=23 students Thermofluid survey and n=12 for the Mechanical survey.

a. Student self-confidence

After completing the four-week, full-scale laboratory module, our survey data indicated that 91% of the students (n=157) are confident or very confident in applying the same ASTM standard in the future, and 78% are confident or very confident in following a new ASTM test standard. In the pilot laboratory module, our survey data indicated that 100% of the students (n=35) are confident or very confident in applying the same ASTM standard in the future, and 91% of the students are confident or very confident in following a new ASTM test standard. Figures 2 and 3 present this data comparing the full-scale offering with the pilot course. More students in the Mechanical Case said they were "very confident" than "confident" when responding to these two questions than those surveyed in the Thermofluid Case, disregarding the class sizes. One potential reason is students had been presented with mechanical material testing content in introductory courses but not thermofluid material characterizations. No matter, when comparing the full-scale and pilot offerings, an encouraging result can be seen where most (78%-100%) of the students felt at least confident following the same or future ASTM procedures. The combined topics data is presented in Table 4.

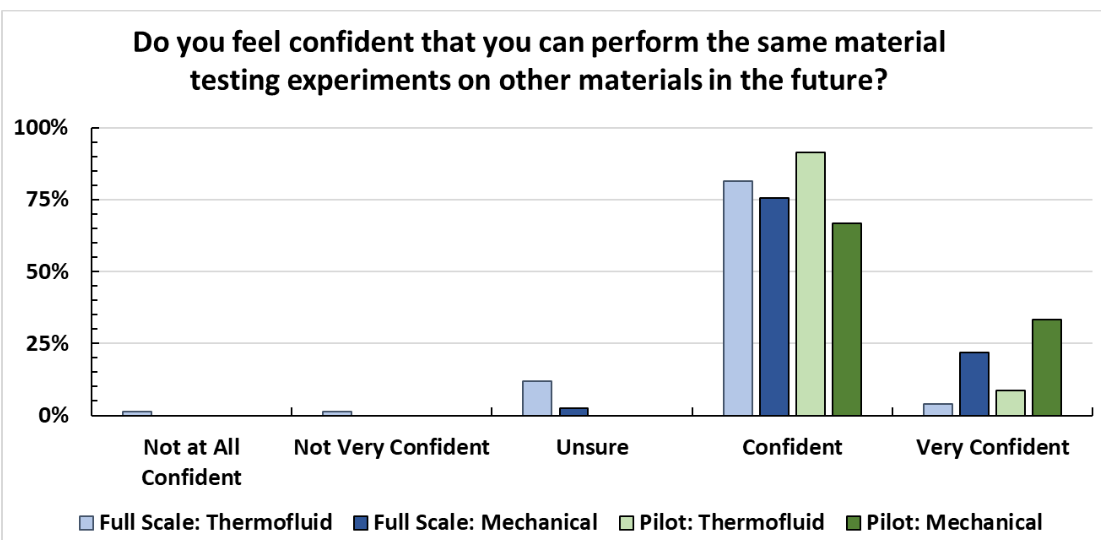

Figure 2. Student confidence level to perform the same material testing experiments. (Full Scale, Thermofluid: n = 75; Full Scale, Mechanical: n =82; Pilot, Thermofluid: n = 23; Pilot, Mechanical: n = 12;)

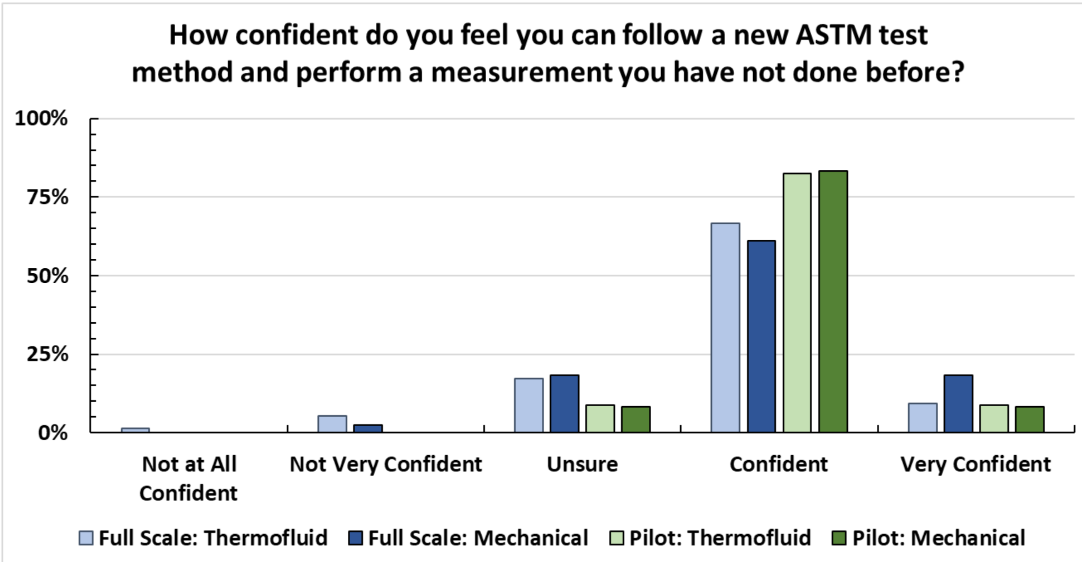

Figure 3. Student confidence level to follow a new ASTM standard in the future. (Full Scale, Thermofluid: n = 75; Full Scale, Mechanical: n = 82; Pilot, Thermofluid: n = 23; Pilot, Mechanical: n = 12;)

Table 4. Comparing Student Confidence Level to Follow a New ASTM Procedure and Perform the Same Material Testing Experiments in the Future in the Pilot and Full-Scale Offering Disregarding Lab Topics. (Combined-topics, Full Scale: n = 157, Pilot: n=35)

Question	New ASTM		Perform future experiments	
Student Answer	**Full Scale**	**Pilot**	**Full Scale**	**Pilot**
Not at All Confident	0.6%	0.0%	0.6%	0.0%
Not Very Confident	3.8%	0.0%	0.6%	0.0%
Unsure	17.8%	8.6%	7.0%	0.0%
Confident	63.7%	82.9%	78.3%	82.9%
Very Confident	14.0%	8.6%	13.4%	17.1%

b. Understand the connections between theory and practice

We added a few questions to the full-scale survey to gauge the effectiveness of the course in demonstrating the practical application of knowledge from previous ME courses. The majority (84%) of the students agreed that the activities helped them understand the real-world application of the theory they had learned. Additionally, 76% of the total students agreed they applied knowledge from their past ME courses to these lab activities. Figures 4 and 5 show that when split by topic, a larger percentage of the students who took the Mechanical Case (85%) felt the course helped them apply previous knowledge than for the Thermofluid Case (65%). The percentage breakdown of this data is presented in Supplementary Table S1.

The required prerequisite knowledge for the course was fundamental circuit analysis, instrumentation, measurement, statistics, engineering computational tools, fluid mechanics, and vibrations. Limited by the curriculum structure and student populations, heat transfer could not be set as a prerequisite or concurrent requirement, even though the concept was heavily applied in this course. Students who followed the suggested academic plan should have completed theory courses for material structure and properties and enrolled in the heat transfer course simultaneously. Potentially, this explained the increase in neutrality in applying previous course knowledge for the Thermofluid students since not all students had previous Heat Transfer experience.

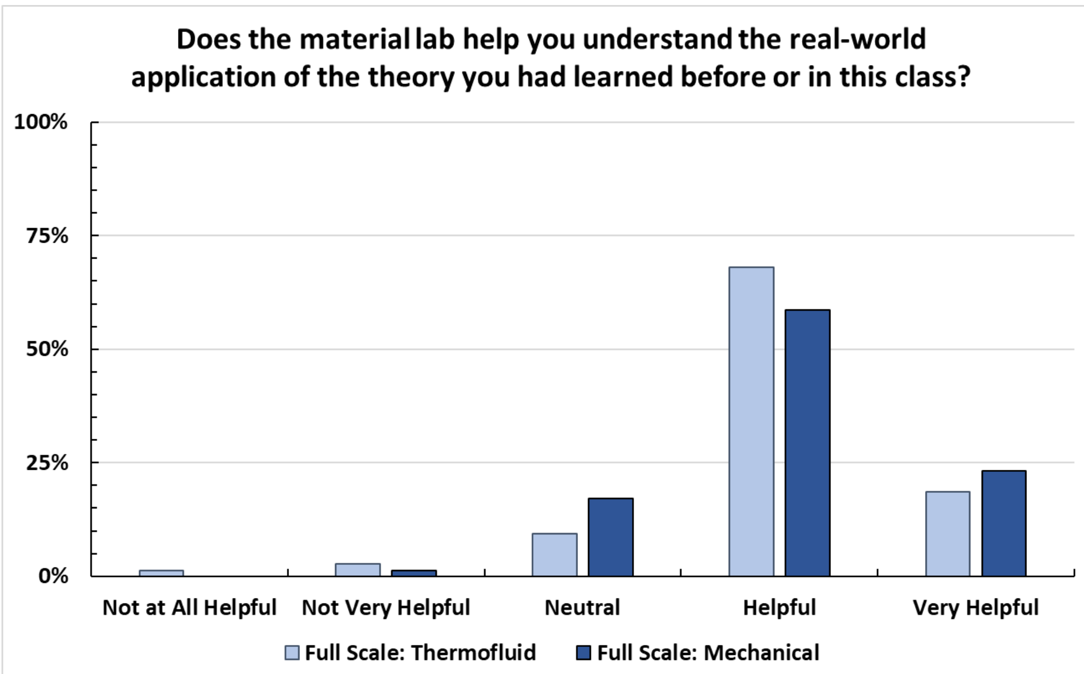

Figure 4. Student's rating of the effectiveness of the course to help them understand the real-world application of the theory (Thermofluid: n = 75; Mechanical: n = 82)

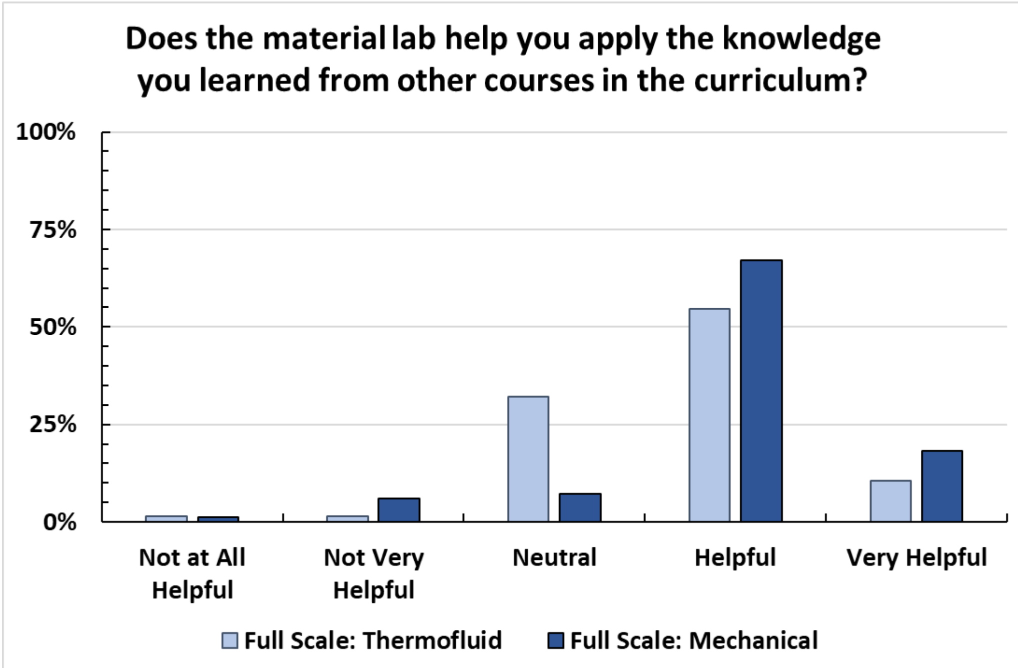

Figure 5. Student's rating of the effectiveness of the course to help them apply previous curriculum knowledge (Thermofluid: n = 75; Mechanical: n = 82)

c. Evaluate the effectiveness of different built-in activities

We compared the effectiveness of six different activities in encouraging students to read and understand the ASTM standard. The six activities included lectures, prelab and discussion questions, the Kahoot trivia game, hands-on lab experiments, lab reports, and assignments. Consistently, hands-on experiments were the most encouraging activities rated by students disregarding the class size and topic types. We observed a change in the students' rating of the helpfulness of the Kahoot! activities to encourage reading the ASTM standards based on class size and topic types. Figure 6 compares six different activities where Kahoot! ranged from the second most encouraging activity to the fourth when the class size and topics changed. The percentage breakdown of this data is presented in Supplementary Table S2. From these results, the students did not highlight the lecture and assignment activities in encouraging their reading and understanding of the ASTM standards. This met our expectations as the ASTM standards were only introduced in these activities and were not a focus. The one exception was, in the pilot's thermofluid case, there was an assignment with an ASTM portion. The assignment portion was removed for the full-scale offering as it was a duplicated effort better suited for the lab report.

From the full-scale course, more than half (54%-64%) of the students said the Kahoot! Trivia games were helpful, and they rated them as interesting or very interesting. Table 5 compares the percentage data for these questions where a larger percentage of the students found the Kahoot! Trivia games helpful and interesting.

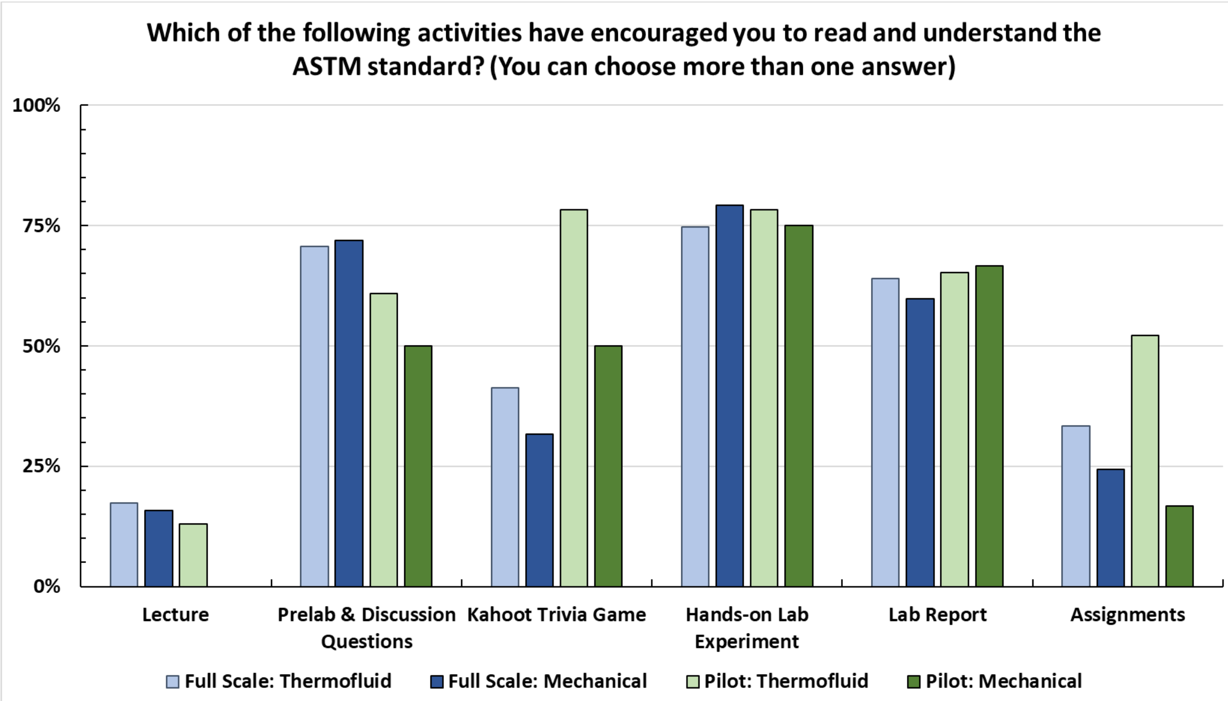

Figure 6. Student's selection of which course items encouraged them the most to read and understand the ASTM standards (Full Scale, Thermofluid: n = 75; Full Scale, Mechanical: n = 82; Pilot, Thermofluid: n = 23; Pilot, Mechanical: n = 12;)

Table 5. Student's Rating of Their Interest Level and Helpfulness of the Kahoot Trivia Games Used in the Full-scale Course (Thermofluid: n = 75; Mechanical: n = 82)

Question	The interest level in Kahoot!		Helpfulness of Kahoot with ASTM	
Student Answer	**Full Scale Thermofluid**	**Full Scale Mechanical**	**Full Scale Thermofluid**	**Full Scale Mechanical**
Not at All Interesting/Helpful	2.7%	2.4%	4.0%	6.1%
Not Very Interesting/Helpful	9.3%	8.5%	6.7%	4.9%
Neutral	30.7%	35.4%	25.3%	29.3%
Interesting/Helpful	36.0%	39.0%	49.3%	43.9%
Very Interesting/Helpful	21.3%	14.6%	14.7%	15.9%

V. Lessons Learned

a. Creating laboratory courses that connect engineering standards, students' prior knowledge, and real-world applications

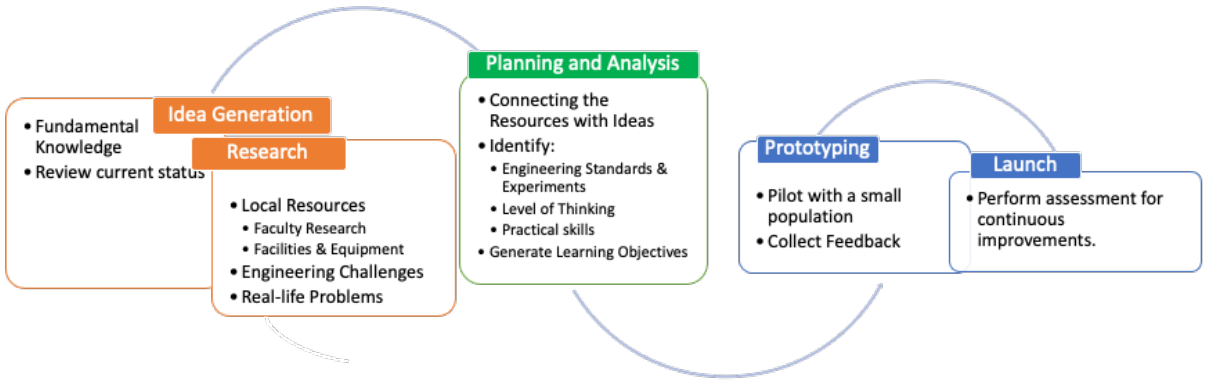

Figure 7. Applying the product development process to develop a laboratory course that connects engineering standards, students' prior knowledge, and real-world applications.

The two laboratory modules discussed in this paper were part of our department's laboratory renovation project. Our team was tasked with designing, developing, and teaching the new laboratory course to replace the preexisting laboratory course in the previous curriculum. The comprehensive details of the project and the complete course design can be found in our earlier publication [2]. For creating the two laboratory modules presented in this paper, we followed a traditional product development process, as illustrated in Figure 7. We generated our ideas by reviewing our curriculum's required course content and listing the most critical topics in the Materials domain. In addition, we evaluated our existing material laboratory course content and summarized the pros and cons. Then, we researched individual faculty research specialties in the department, the NAE grand challenges of engineering [13], and daily engineering problems students might be interested in. For institutes with existing equipment, which is different from our case, summarizing a list of existing equipment could be beneficial in the research phase. After gathering the above ideas and research results, we analyzed the data and connected the dots. We found brainstorming mind maps or other visualization tools and discussions with faculty who worked in the selected field helped generate and organize ideas. Our goal at the connecting the dots stage was to find a research question or engineering problem related to a few critical topics. Once the question or problem was selected, we identified related engineering standards and tests to be conducted in the laboratory module. Then, we correlated the experiment to the goal of practical skills students should demonstrate. This goal guided us on how much data analysis students should perform in the lab. Since our goal was set to strengthen students' data analysis skills, raw data was provided to students to perform data and statistical analysis. If our practical skills goal was set on critical thinking, we would choose to allow students to use processed data from material testing software and concentrate on solving the problem. We used the level of cognitive skills students should achieve to tailor our experiment's complexity. Our labs were geared toward students' abilities in remembering, understanding, and applying their knowledge and engineering standards. Therefore, many experimental procedures were structured with terminologies similar to the ASTM standards. This tested students' understanding of different tasks, for example, selecting the operating parameters, choosing reporting format, and extracting experimental results from raw data. Students' abilities to apply their engineering knowledge were revealed when students used their measurement data on theoretical calculations to solve the given problem. Some higher cognition skills activity was embedded in our module to prepare students for the next level of the course. For example, students had to evaluate their measurement results to predict the actual material types. After the course's details were planned and course materials were developed, it was critical to pilot the course materials in a smaller class, collect student feedback, evaluates the needs of supporting materials, record commonly asked questions, develop teaching assistants training documents, and adjust teaching material before fully launching it to all students. We suggested that course assessments be maintained after the course is launched for continuous improvement.

Below is a list of questions educators could consider in the planning and development phases of designing a laboratory experience that connects engineering standards, students' prior knowledge, and real-world applications.

Idea Generation:

- Review the required courses in the curriculum and list all the most important topics within the domain you want to emphasize.

Research:

- What local resources do you have?
- What are the research specialties of your institute and department?
- Who are the colleagues that can support your development?

Analysis and Planning:

- Review the answers to the above questions and connect the dots.
    - What kind of real-life question can connect a few important engineering topics (listed in idea generation) with the available resources?
    - Can we connect the department's research strength to teaching?
- Once the real-life question is defined,
    - What characterization tests should be performed?
    - Which engineering standards should students follow?
    - What are the practical skills students practice in these labs?
- Lastly, define the learning objective by considering the cognitive skills level you want students to achieve with the in-lab activities.

b. Using Game-based Strategies in Teaching

The use of game-based strategies in education has been shown to bring numerous benefits to students. Game-based learning has been shown to have a positive effect on undergraduate education and can increase student engagement and motivation, leading to a more enjoyable learning experience[14], [15]. Additionally, Kahoot trivia games have been found to boost student motivation and knowledge acquisition [16]–[18]. Therefore, Kahoot! Trivia games were used in this lab as bonus points to motivate students to read the ASTM standards. Due to positive feedback from this trivia game, another Kahoot! was used in this module as a step-by-step walkthrough of an ε-NTU radiator analysis. The ε-NTU example game followed a pattern to guide the students through the analysis. First, they had to verify the parameters of the problem, then identify the correct form of the equations, and lastly, perform calculations per the given values. This process was repeated until the analysis was complete.

By having the students work through an example problem in class, they were able to compare their results at each step of the problem with multiple-choice answers and receive immediate feedback on their understanding of the problem. This also provided an opportunity for the instructor to address common mistakes at each step of the problem and to verify the correct answer with the whole class before continuing with the example. The multiple-choice options were chosen based on answers the students could get if they made a common mistake. This included wrong assumptions and, most importantly, incorrect units.

The use of game-based strategies in this course encouraged the students to read the ASTM standards outside of the classroom and test their understanding of the main concept being taught in the module. Educators can consider a similar approach to increase attention in the classroom and provide an opportunity to address class-specific weaknesses.

VI. Future Work

This paper summarized our course design strategies and preliminary student feedback. Two main focuses were on students' confidence level in transferring their learning to new situations and their perspective in understanding the connection between theory and practice. To conclude the impact of the presented approach, formative and summative assessments using subjective and objective data will need to be evaluated in the future.

The survey presented in this paper was designed to gather student feedback after completing the module. Future surveys capture the student's pre, and post-lab knowledge will allow direct evaluations of the course's effectiveness in supporting students to master their understanding. In addition, designing assessment tools to collect subjective data from prerequisite courses on student ability to solve real-world problems and compare them to student performance in this laboratory course will evaluate the course's impact in preparing students to bring theory to practice. Furthermore, adding senior exit-survey questions to re-assess student confidence levels in knowledge transfer will allow evaluations of the long-term impact of the design strategy.

With this information, we believe we can continue to modify and evolve this laboratory course design strategy to strengthen students' ability to understand and apply engineering standards and lead them to engage in higher-order thinking skills.

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Appendix

Supplementary Table S1. Percentage Breakdown of Students' Rating of the Effectiveness in the Full-Scale Course to Help Them Understand the Real-World Application and Apply Previous Curriculum Knowledge Presented in Figures 4 and 5.

Question	**Real-World Application**		**Apply Course Knowledge**	
Student Answer	**Thermofluid**	**Material**	**Thermofluid**	**Material**
Not at All Helpful	1.3%	0.0%	1.3%	1.2%
Not Very Helpful	2.7%	1.2%	1.3%	6.1%
Neutral	9.3%	17.1%	32.0%	7.3%
Helpful	68.0%	58.5%	54.7%	67.1%
Very Helpful	18.7%	23.2%	10.7%	18.3%

Supplementary Table S2. Percentage Breakdown of the Student's Selection of Which Course Items Encouraged Them the Most to Read and Understand the ASTM Standards Presented in Figure 6.

Question	**Activities that Encouraged Reading and Understanding ASTM**					
Student Answer	**Full Scale Thermofluid**	**Full Scale Mechanical**	**Full Scale**	**Pilot Thermofluid**	**Pilot Mechanical**	**Pilot**
Lecture	17%	16%	17%	13%	0%	9%
Prelab & Discussion Questions	71%	72%	71%	61%	50%	57%
Kahoot Trivia Game	41%	32%	36%	78%	50%	69%
Hands-on Lab Experiment	75%	79%	77%	78%	75%	77%

Lab Report	64%	60%	62%	65%	67%	66%
Assignments	33%	24%	29%	52%	17%	40%